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ECONOMIC ASSESSMENT OF CLIMATE CHAGNE IMPACTS ON BIODIVERSITY, ECOSYSTEM SERVICES AND HUMAN WELL-BEING

An Application to European Forest Ecosystems

SETTORI SCIENTIFICO-DISCIPLINARI DI AFFERENZA:
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Tesi di dottorato di Hongyu Ding, matricola n.955424

Direttore della Scuola di dottorato
Prof. Carlo Giupponi

Tutori del dottorando
Prof. Carlo Carraro
Dr. Paulo A.L.D. Nunes

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PhD Dissertation

Economic Assessment of Climate Change Impacts on Biodiversity, Ecosystem Services and Human Well-being

- An Application to European Forest Ecosystems -

by
Hongyu Ding

-January 2011-

Department of Economics, Ca'Foscari University of Venice, Italy

This work is dedicated to my beloved parents

(仅以此论文献给我挚爱的父亲母亲)

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For every Creature of unfallen Nature,
call it by what name you Will,
has its Form, and Power, and State,
and Place in Nature,
for no other End,
but to open and enjoy,
to manifest and rejoice in some Share of the Love,
and Happiness, and Goodness of the Deity,
as springing forth in the boundless Height
and Depth of Nature.

'The Spirit of Love' - William Law (1754)

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Helen Ding
18 January 2011, in Venice

SUMMARY

This doctoral dissertation is inspired by the major environmental and socio-economic challenges faced by biologists, climate scientists, economists and policymakers today, and is dedicated to the state-of-the-art literature in the cross-cutting research area where biodiversity economics and climate economics blend. In particular, this work is conducted by (1) developing a holistic, well-accepted approach that explores the mapping of complex links between climate change, biodiversity, ecosystem services and human welfare in numerical terms; (2) further extending the state-of-the-art methodologies so as to monetize the climate change induced impacts on biodiversity, ecosystem services and human wellbeing; and, (3) promoting and discussing the incorporation of the valuation results into the support of policy making, including ecosystem-based climate change mitigation policies as well as ecosystem-based welfare re-distributional policies. Finally, this dissertation demonstrates that the implementations of social and environmental policies are not always conflicting, but rather supplementary to each other.

SOMMARIO (IN ITALIAN)

Questa dissertazione trae ispirazione dalle grandi sfide ambientali e socio-economiche che biologi, scienziati climatici e decisori oggi devono affrontare, e si focalizza sullo stato dell'arte di quell’area di ricerca, dove economia della biodiversità ed economia del clima si fondono. In particolare, questo lavoro si propone di (1) sviluppare un approccio olistico che esplora empiricamente la complessa rete d’inter-relazioni tra cambiamenti climatici, biodiversità, servizi dell’ecosistema e benessere umano; (2) estendere le metodologie, comunemente utilizzate in letteratura, in modo da monetizzare gli impatti generati dai cambiamenti climatici su biodiversità, servizi dell’ ecosistema e benessere umano; (3) promuovere e discutere l’introduzione della valutazione ambientale come supporto per le decisioni, per esempio includendo delle politiche di mitigazione dei cambiamenti climatici oppure redistributive del benessere tutte incentrate sull’ecosistema. In conclusione il lavoro dimostra come la realizzazione di politiche ambientali non sia sempre in contrasto con le politiche sociali, ma piuttosto possa essere fonte di sinergie.

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CHAPTER 1 INTRODUCTION

1.1 Motivation

The publication of *The Economics of Climate Change: the Stern Review* in 2006 (Stern, 2006) has inspired an unprecedented outpouring of high quality economics articles on climate change ever since (Heal, 2008). Neoclassical economic theories have been extensively applied in the estimation of the costs of climate change to our economy and have led to a stably growing number of Integrated Assessment Models[1] (IAMs), which integrate the economic aspects of climate change with the science and dynamics of the climate system. In particular, by incorporating a climate change damage function, the IAMs are able to translate a given set of physical, environmental and social impacts into monetary units such as percentage of GDP, at different scales and over time (Bosetti, *et al.* 2009). These results are fundamental to the understanding of trade-offs between avoided impacts and the costs of reducing greenhouse gas (GHG) emissions. However, the current literature has shown, by far, very little effort in the economic valuation of climate change impacts on natural capital and ecosystem services (Tol, 2005; Heal, 2008). In a recent meta-review of climate economic studies (Heal, 2008), Geoffrey Heal commented that "we need to better understand how climate change affects natural capital – the natural environment and ecosystem comprising it – and how this in turn affects human welfare" Today, our research on the impact of climate change on natural capital remains crude within IAMs. In this context, additional research efforts need to be allocated in the development of economic models more disaggregated than those IAMs, which have been used to date, bringing along with it the natural capital/ecosystem services into the analysis (Heal, 2008).

Despite these modeling shortcomings, the role of biodiversity in underpinning ecosystem and supporting human wellbeing has long been a topic of interest in research and public policy. From the 1992 United Nations Conference on Environment and Development in Rio de Janeiro, to the recent major international initiatives, including the 2005 Millennium Ecosystem Assessment (MA)

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[1] Among the many IAMs that have become available in the literature, the most representative can be considered to be the DICE/RICE (Nordhaus and Boyer, 2000 for an exhaustive review), the Mendelshon model (Mendelshon et al., 1998), Fund (Tol, 2002, 2002a), PAGE (Hope, 2003) and MERGE (Manne et al., 1995; Manne and Richels, 2004) models. A first review of these models appeared in Third Assessment Report (IPCC, 2001), which mostly describes the results from Mendelshon, Tol and Nordhaus. Warren (2006) provides an updated review of the FUND, DICE/RICE, MERGE and PAGE models.

promoted by the United Nations' Convention on Biological Diversity (CBD) and the 2008 Economics of Ecosystems and Biodiversity study (TEEB) initiated by the European Commission, the global community has successfully triggered a range of awareness campaigns that promote the understanding of the economic consequences of biodiversity loss and ecosystem degradation to our socio-economic system across the globe. This concept is related to the United Nations' Millennium Development Goals and explores the potential of utilizing natural conservation as an economical substitute to the climate change mitigation technologies (e.g. Reducing Emission from Deforestation and forest degradation in Developing countries - REDD). Most recently, the successes of the two COP meetings held in 2010 (i.e. the UNFCCC-COP16 climate meeting in Cancun and the CBD-COP10 biodiversity meeting in Nagoya) have reaffirmed the crucial importance of biodiversity conservation, realizing its multiple benefits in terms of reducing the atmospheric concentration of GHGs as well as the long-term sustainability of human welfare. Both conferences have reiterated (1) the recognition of biodiversity and ecosystem services value, a feature of all human societies and communities; (2) the role of economic valuation in demonstrating the value of biodiversity and ecosystem services to support decision making; and, (3) the importance of introducing mechanisms that capture and incorporate the values of ecosystems into decision making.

Against this background, this present doctoral dissertation aims to contribute to this challenging research area by addressing economic valuation of biodiversity and ecosystem services in the context of global change, especially climate change. In particular, this work is conducted by (1) building on a holistic, well-accepted approach that explores the mapping of the complex links between climate change, biodiversity, ecosystem services and human welfare in numerical terms; (2) extending the state-of-the-art methodologies so as to monetize the climate change induced impacts on biodiversity, ecosystem services and human wellbeing; and, (3) promoting and discussing the incorporation of the valuations results into policy decision-making, including ecosystem-based climate change mitigation policies (such as REDD) as well as ecosystem-based welfare re-distributional policies such as payments for ecosystem services (PES). As we will demonstrate, the implementations of social and environmental policies are not always conflicting, but rather complementary to each other. For instance, the policies that promote natural conservation and ecosystem protection may also contribute to GHG mitigation and offer food and job opportunities to the local communities through various ecosystem services provided.

1.2 Research Framework

(1) Understanding climate change impacts on biodiversity, ecosystem services and human wellbeing

The impact of climate change is multidimensional and involves interactions among three systems: *the climate system, the ecological system and the socio-economic system*. Figure 1 below shows how these systems interact with each other through four key components: biodiversity, ecosystem services, GHG emissions and human wellbeing. Among all others, biodiversity plays a fundamental role in conjoining the three systems together. For this reason, we shall start our illustration from the ecological system that biodiversity underpins.

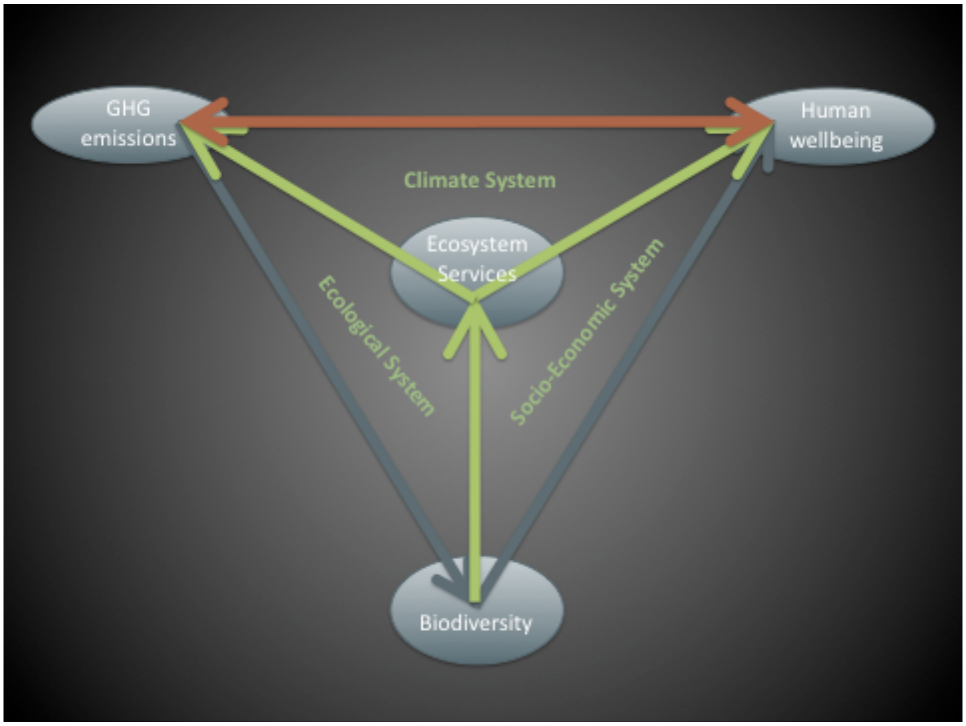

Figure 1. Graphic illustration of interactions between climate change, biodiversity, ecosystem services and human wellbeing

<u>*The ecological system*</u>

Biodiversity by definition encompasses the variety of life on earth from genes to species, through to the broad scale of ecosystems across time and space. It is important in terms of determining the health of ecosystem, ensuring the stability and productivity of ecosystems, as well as underpinning the supply of an array of ecosystem services that contribute directly and indirectly to human wellbeing. In this regard, the term "biodiversity" is used largely as an assumed foundation for ecosystem processes, rather than simply the number of species on a species list. Moreover, biodiversity also interacts with the global climate system in two opposite dimensions. On the one hand, GHGs accumulated in the atmosphere will increase the Earth's surface temperature, which will very likely shift the distribution of species, change composition of ecosystem, and thus influence the overall supply of ecosystem goods and service, including the carbon regulation service. On the other hand, biodiversity and its underpinning ecosystems provide regulating services that sequester CO_2 emissions concentrated in the atmosphere and so regulate the climate system, preventing continual global warming. Therefore, climate change combined with biodiversity loss may consequently weaken the capacity of ecosystems to mitigate CO_2 concentration in the atmosphere.

The climate system

The global climate system is connected with both the human socio-economic system and the biological system through the change of chemical composition of the atmosphere. There is new and stronger evidence that most of the warming over the last 50 years is attributable to human activities, such as coal and oil based energy generation, cultivation, deforestation and other land use changes that have greatly induced increases in atmospheric concentrations of carbon dioxide, methane, and nitrous oxide (IPCC, 2007). In return, human beings have experienced and will continue to suffer from the consequences of climatic variations through the changes of environment, degradation of biodiversity and ecosystems, more severe droughts, outbreaks of human disease, as well as the reduction of agricultural and meat production. The natural regulation of the global climate system, to a greater or less extent, relies on various types of ecosystems on earth, including the oceans, ice sheets (cryosphere), living organisms (biosphere) and soils, sediments and rocks (geosphere). In particular, trees and plants in forest ecosystems have the ability to reduce the atmospheric concentration of CO_2 through the photosynthesis process, significantly weakening the Earth's natural greenhouse effect, and reducing the Earth's surface temperature.

The socio-economic system

Mounting population, changing diets, urbanization, land-use changes and climate change are the major social-economic pressures on biodiversity, causing species to vanish at an alarming rate all over the world. This in turn can significantly affect the stability of ecosystem functioning and their capacity to retain the provision of ecosystem services to humans. Today, more than ever, there is worldwide concern about the relevance of biodiversity to environmental quality and its impact on human welfare. The worldwide decay in environmental quality and the gradual depletion of natural resources, sometimes referred to as the 'new scarcity', has prompted intense scientific attention in both the natural and social sciences. In addition, as personal incomes rise and leisure time becomes more freely available in the developed world, concern for more immediate human needs is accompanied by interest in nature preservation and conservation for future generations. Consequently, the 'new scarcity' has spatial and temporal horizons that extend far beyond the current level of thinking and acting.

(2) Understanding the welfare impacts of climate change induced biodiversity loss

As previously mentioned, biological diversity represents the natural wealth of the Earth, and provides an important basis for life and prosperity for the whole of mankind, through the provision of "ecosystem services" at different levels, ranging from local biodiversity benefits of harvest potential and tourism revenues to the global benefits such as carbon sequestration and genetic information. Thus, human wellbeing, to a certain extent, is dependent upon biodiversity and its underpinning ecosystem goods and services and the welfare impact of biodiversity loss and ecosystem degradation is not restricted to local populations but exists also at national, regional and international levels.

From a welfare economics standpoint, biodiversity degradation and the reduction of the underpinning Ecosystem Goods and Services (EGS) constitute a typical example of a public good, whose value is not properly encapsulated in the prices of commodities sold in the market place. Therefore, it requires a governmental structure that assures their use and conservation is effectively regulated. In this regard, studies that recognize, demonstrate and eventually capture the biodiversity benefits have a crucial role to play in supporting policy making, in terms of identifying policy priorities, evaluating trade-offs of different policy targets, designing cost-effective policy instruments, so that economic incentives can be created and stimulated to preserve biodiversity and to retain the multiple associated benefits. In order to illustrate the interactions and interdependence among the economic, socio-cultural, and ecological factors, we adopt a well-known Millennium Ecosystem Assessment (MA) framework that begins with analyzing a set of major socio-economic and environmental drivers, in particular climate change, that are responsible for the changes in biodiversity and ecosystem, influence their provision of supporting, provisioning, regulating and cultural services, which are ultimately linked to human well-being (MA, 2005). As shown in Figure 2 below, the MA approach clearly and comprehensively illustrates the links between biodiversity and human wellbeing, which are often non-linear and complex. In this context, the economic analysis of biodiversity benefits is anchored in welfare economics theory, identifying ecosystem services as important constituents of human wellbeing. Thus, the MA classification of ecosystem services is at the foundation of the economic valuation exercises presented in current research.

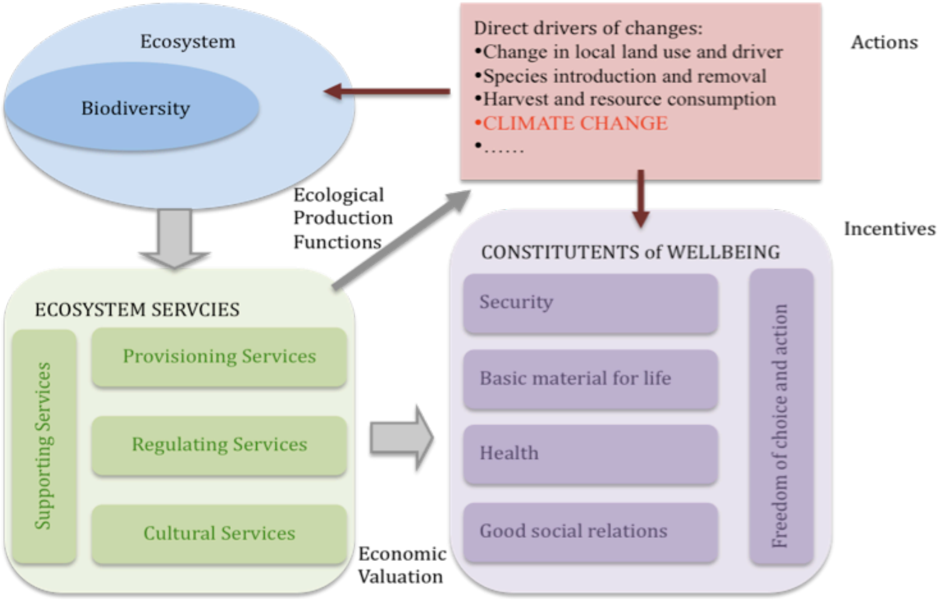

Figure 2. An analytical framework to link biodiversity, ecosystem services and human wellbeing (Source: MA (2005), adapted)

1.3 Objectives and Outline of the Study

This doctoral dissertation seeks to achieve the following **research objectives**:

(1) *Explore the use of an ecosystem-based valuation approach to estimate the welfare impacts as a result of climate change induced changes in biodiversity and provision of ecosystem goods and services*;

(2) *Explore the potential for general equilibrium models to incorporate climate change induced welfare changes at a larger geographic scale and map winners and losers across world regions;*

(3) *Explore the use of econometric tools to analyze and estimate the links between biodiversity, ecosystem services and human wellbeing in the context of climate change;*

(4) *Explore the use of GIS mapping tools in terms of spatial analysis of the social dimension of biodiversity policy and its application to the design of more efficient and cost-effective policies for biodiversity conservation and poverty alleviation.*

The sequence of the dissertation follows the objectives set out above. The four objectives are researched in the form of four individual peer-reviewed papers, in which key research questions are addressed, making use of different methodologies as appropriate. Results will be reported and discussed in the end of each chapter. The structure of the doctoral dissertation is organized as follows.

Chapter 2 begins with a comprehensive economic valuation of climate change impacts on the forest ecosystem services of Europe. This valuation exercise stems from micro-economic theory and builds upon the MA conceptual framework, considering biodiversity as the underpinning of ecosystems and ecosystem services, which in turn contribute to human wellbeing. The proposed economic valuation analysis follows a three-step approach. The first step is the determination of the role of biodiversity in the creation of relevant ecosystem services. The second step is the calculation of the reduced quantity and quality of these ecosystem services resulting in losses to human welfare under alternative climate scenarios. The third step is the (monetary) valuation of those losses. These steps are at the core of micro-economic analysis of regional climate change impacts, exploring the use of both market and non-market valuation techniques. For this reason, we label this integrated valuation method as a *hybrid valuation model.* In addition, spatial issues related to climate change are considered in the valuation process by classifying forest biomes in terms of geo-climatic regions. Thus, our valuation results reaffirm that climate change affects forest ecosystem and their functioning differently across geo-climatic regions. This effect is associated with certain degrees of welfare impacts that are unevenly distributed across Europe. Finally, we show that climate change impacts vary also depending on the type of ecosystem services under consideration.

Chapter 3 moves the focus of this research towards the exploration of the potential to incorporate micro- and macro- economic analysis in the estimation of the socio-economic impacts of climate change-induced changes in biodiversity and ecosystems. Biodiversity and ecosystem services are interpreted as important components of the world economic system, where markets interacting through exchanges of inputs, goods and services respond to changes in relative prices induced by climate shocks, explicitly describing market-driven or autonomous social-economic adaptation. Therefore, by developing a partial-general equilibrium valuation framework, we are able to incorporate ecosystem services into a macro economic mechanism, where the world economy is assessed by a set of computable general equilibrium (CGE) models. Within this framework, changes in carbon sequestration provided by European forests are incorporated into a CGE model through a global warming approach, which allows us to take into account the climate change impacts on forest carbon sequestration services and to re-compute a temperature equivalent induced by the higher release of CO2 emissions in the atmosphere resulting from climate change. On the basis of this new information, we then re-estimate all of the climate change impacts considered using the CGE model and recalculate new macro-regional GDP effects. The differences between climate change impacts on GDP considering the original and the new carbon sequestration levels are used as an approximation of the general equilibrium value of the changes in the European forest carbon sequestration service. This innovative approach allows us to explore the scaling-up potential of regional climate change impacts on biodiversity and ecosystem services and to identify the winners and losers of climate change impacts at a larger geographic scale.

Chapter 4 conducts an empirical investigation on the complex relationship between biodiversity and the values of ecosystem goods and services that are supported by biodiversity and ecosystem functioning, aiming to produce an econometric quantification of the magnitudes involved. Furthermore, we operate this study in the context of global climate change. Climate change, here interpreted as increase in temperature, is one of the major drivers today that alter the pattern of biodiversity distribution, affect ecosystem functioning and change the flows of ecosystem goods and services provided by a healthy ecosystem. Therefore, it is an essential first step to construct suitable biodiversity metrics for the purpose of our research. The biodiversity indicator is constructed by exploring the use of the concept of Natural Capital Index (NCI) that contains information regarding the quantitative and qualitative changes of ecosystems driven by various direct and indirect socio-economic factors, including global warming. Furthermore, information regarding biodiversity changes expressed by the biodiversity indicator is integrated into the econometric specification so as to capture the marginal impacts of changes in biodiversity on the value of ecosystem goods and services due to climate change. The results of this study will contribute to a better understanding of the marginal impact of global warming in different regions of the world, and recognize the synergies of biodiversity conservation strategies and climate policies, which allows for more efficient allocation of resources among groups of people.

Chapter 5 explores the use of spatial mapping tools, including Geographic Information Systems (GIS) to explore the social dimension of biodiversity policy, so as to identify and analyze the strength of the linkage between biodiversity and human livelihoods in different geographic locations. Our analysis is focused on Europe, where biodiversity and ecosystem benefits have been well studied for many ecosystems and will concentrate in particular on forest, coastal and wetland ecosystems both at country level and downscaled to a higher geographical resolution. In particular, we focus on European rural areas with a high density of agricultural land-use and investigate the dependencies between the socio-economic, biodiversity and ecosystem value indicators in the selected rural regions across different income groups. Moreover, social vulnerability indicators are also identified and mapped in a spatial gradient so as to investigate the role of biodiversity in the definition of social vulnerability contours maps in particular for rural communities living in remote regions. The results of this study are expected to provide important insights for EU policymakers to design potential policy instruments that can on the one hand promote biodiversity conservation and prevent natural resources from degradation, and on the other hand contribute to social stability and human livelihoods.

Chapter 6 draws general conclusions from this research, outlines some policy recommendations and discusses the directions for future research.

CHAPTER 2 VALUING THE CLIMATE CHANGE IMPACTS ON EUROPEAN FOREST ECOSYSTEMS INTO THE FUTURE

Ding, H., Silvestri, S., Chiabai, A., P.A.L.D.Nunes (under review) 'Valuing the climate change Impacts on European Forest Ecosystems into the Future', submitted to *Journal of Ecological Economics*

Abstract

This paper presents one of the first attempts to value climate change impacts on human welfare through assessing altered forest ecosystems and their capability of delivering ecosystem services to humans, The well-known MA approach is anchored in the valuation exercise, which allows the comprehensive quantification of ecosystem services provided by forest ecosystems and forms the solid ground for economic valuation practice from a microeconomic perspective. This study focuses on a European scale and potential welfare impacts caused by changing climate are assessed across latitudes in Europe and reported in terms of four future storylines developed by the Intergovernmental Panel on Climate Change (IPCC) for each country under consideration. Our results show that climate change induced welfare impacts vary across latitudes depending on the nature of the forest ecosystem services and the storyline where we stand. The economic magnitudes of climate change impact on forest ecosystems may contribute to a better understanding of the potential welfare losses across different regions and to identification of winners and losers as a result of future climate change. This will have important policy implications to reallocate resources among Europe countries to cope with the continuous climate change.

Keywords: European forest assessment, ecosystem goods and services (EGS), climate change impact, IPCC scenarios

JEL: Q23, Q51, Q54, Q57

Note: An earlier version of this manuscript has been presented in 2009 EAERE conference, held in Amsterdam, the Netherlands and has been included in the Conference Proceedings.

2.1 Introduction

Evidence has shown that rapid climate change has significantly affected natural environment in terms of accelerating the loss of biodiversity and the degradation of ecosystem's health over the last 50 years and the impacts will intensify in the future (MA, 2005; IPCC, 2007a). This led to an increasing literature in identifying, quantifying and mapping biophysical impacts caused by climate change, which is however not always followed by an assessment of the welfare losses involved. In a recent literature survey, Tol (2008) showed an exponential increase in the number of papers published in international peer reviewed journals on the topic of climate change, jumping from 1,714 papers in 1995 to 11,652 papers in 2008. Among all the reviewed climate literature, only a very small proportion has centred within the economics literature (about 33 papers in 1995 and 218 papers in 2008), most of which have focused on market-related impacts of climate change (Tol, 2005). The use of a monetary metric to express economic impacts of climate change on biodiversity and ecosystems performance is often missing due to a lack of recorded market information (Pearce et al., 1996; Tol 2005). In addition, despite our advanced knowledge of climate change impacts, there is still uncertainty issue around the projection of these impacts into the future and the quantification of them in monetary terms. Under this background, the present paper represents one of the first attempts in the literature to fill this gap by undertaking an empirical application of economic valuation techniques to estimate the economic impacts of climate change on ecosystem services at an European scale. These results anchored in the expertise from both the fields of natural sciences and economics can play a crucial role in enabling policy options moving forward against global warming.

The assessment of the welfare impacts of climate change for the European forests is approached within the DPSIR framework (OECD, 1999), which captures the causal relationship between climate change, biodiversity, forest ecosystems and human well-being – see *Figure 1.*

The figure implies that climate is an integral part of ecosystems and organisms have adapted to their regional climate over time. Climate change is already having an impact on ecosystem and biodiversity in various world regions, in particular on the high-altitude and high-latitude ecosystems (IPCC, 2002). Projections suggest if global mean temperatures exceed 2-3 °C within this century, climate change will become a progressively more significant threat to ecosystem through changing species distribution, population sizes, the timing of reproduction or migration events as well as through increasing the frequency of pest and disease outbreaks (IPCC, 2007b; CBD, 2010; MA, 2005). Since human societies depend on ecosystems for the natural, cultural, spiritual, recreational and aesthetic resources they provide, climate change induced ecosystem distortion may ultimately influence human well-being by decreasing the quantity or quality of total ecosystem benefits, which in turn can be translated into significant social costs to human society. Therefore, policy actions are needed to halt climate change and sustain the supply of ecosystem services. Yet it is important to note that some ecosystems such as forest ecosystem also engender feedback effects to stabilize climate conditions by sequestrating CO_2 emissions in the atmosphere. These are important ecosystem benefits to be considered in the design of sustainable forest management (SFM) strategies, with a potential impact on future land-use changes. In this regards, the present paper which aims at realizing the changes of costs and benefits as a result of climate change impact on ecosystems will have practical meaning for directing both national and international coping strategies to fight against climate change and to conserve biodiversity and ecosystems.

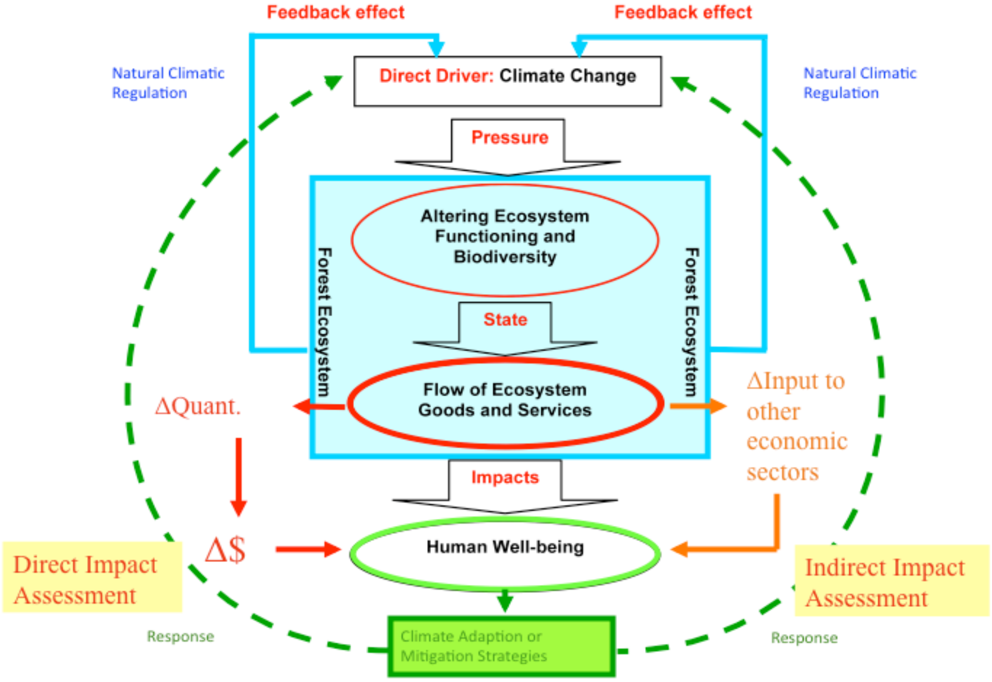

Figure 1.Conceptual model for the climate change, forest biodiversity and human well-being interactions

The paper is organized as follows. Section 2 introduces climate change scenarios presented by the Intergovernmental Panel on Climate Change (IPCC) and geo-climatic classification of European Forests, where the current status of the forests will be discussed.. Section 3 reports the projection of future trends of European forests under alternative climate change storylines, including the changes in forest area and quantity of a variety of ecosystem services under consideration. Section 4 develops an integrated-hybrid economic valuation approach that is applied to assess, in monetary terms, the welfare changes involved in alternative future scenarios. Section 5 concludes with the main findings and sheds lights on the policy implications of this study.

2.2 Climate Change Impacts and European Forest Ecosystems

2.2.1 Key Assumptions of Climate Change Scenarios

Over the last 30 years, the world has experienced significant temperature increases, particularly in the northern high latitudes (IPCC, 2001). Scientists participated in IPCC predict that the average temperature in Europe will increase from 2.1 to 4.4°C by 2050 varying across latitudes, but with the strongest consistent increase in the higher latitudes. In addition, model simulations also suggest a decrease in precipitations in the south of Europe, particularly in summer, but an increase in precipitation over much of northern Europe (Schöter *et al*., 2005). In order to quantify the magnitude of the climate change impacts on forest ecosystems, both quantitative and qualitative data are needed to describe the current state of ecosystems in terms of providing various ecosystem goods and services (EGS) and to project the future changes of EGS in the context of climate change. Before, however it is necessary to identify the possible range of climate change by developing future scenarios. Scenarios include a description of the current situation as well as of the series of events that lead from the current to the future state. The development of scenarios requires a consistent and coherent set of assumptions on the phenomena and processes analysed, their determining factors and expected future development. In this study, we built future climate change scenarios by 2050 based on the four storylines reported by the IPCC Special Report (2000) on Emission Scenarios, namely A1FI, A2, B1 and B2 storylines. These are correspondent to different states of the world, all anchored in a coherent, integrated global circulation model (GCM) (including the Hadley Centre Couplet Model Version 3 (HadCM3) coupled atmosphere-ocean GCM as described by Gordon et al. (2000)) with socio-economic storylines, so as to bring together population growth, land use, CO_2 concentration, temperature, and precipitation (Nakicenovic and Swart 2000; Schöter et al. 2004; Schöter et al. 2005) – see Table 1.

Table 1. The specifications of the four IPCC storylines

Indicator	Climatic model - HadCM3 (Scenarios by 2050)			
	Storyline A1FI Global economic	Storyline A2 Local economic	Storyline B1 Global environmental	Storyline B2 Local environmental
Population (10^6)	376	419	376	398
CO_2 concentration (ppm)	779	709	518	567
Δ Temperature (°C)	4,4	2,8	3,1	2,1
Δ Precipitation Europe (%)	-0,5	0,5	4,8	2,7
Socio-economic dimensions	High savings and high rate of investments and innovation	Uneven economic growth, high per capita income	High investment in resource efficiency	Human welfare, equality, and environmental protection

(Source: adapted from Schröter *et al.*, 2005; IPCC, 2001)

According to the IPCC specifications, A1FI, A2, B1 and B2 storylines are distinguished in terms of four future development paths, i.e. 'global economic' oriented, 'regional economic' oriented, 'global environmental' oriented, and 'regional environmental' oriented, respectively. The two economic oriented scenarios (A1FI and A2) focus on 'material consumption', although A1 scenarios also consider different combinations of fuel, including the A1FI fossil intensive scenario. While the two environmental oriented scenarios (B1 and B2) mainly concentrate on the concepts of 'sustainability, equity and environment'. It is important to point out that, amongst others, the A2 storyline and scenario family describes a very heterogeneous world which is characterized by high population growth, regional oriented economic development, and fragmented and slow per capita economic growth and technology, following the current socio-economic development pattern. For this reason, A2 is frequently used by the European Commission as the baseline scenario, which allows us to run a comparative analysis of three other scenarios against the baseline. We focus, in particular, on the comparison of A2 vs. A1, assessing the changes towards a more economically focused world. Alternatively, we may also consider A2 vs. B1 and B2, assessing the changes towards a more sustainably orientated world.

2.2.2 Geo-climatic Mapping of Forest Ecosystems in Europe

European forest in the present paper comprises forests of 34 countries[2] selected from the *European Forest Sector Outlook Study 1960-2000-2020 main report* (UNECE/FAO, 2005). Total forest area under consideration covers about 185 million ha in 2005 (FAO/FRA, 2005), accounting for 32.7% of the combined territories. The composition and distribution of forest biomes are unevenly distributed across Europe, subject to the local climate conditions – see Figure 2 below.

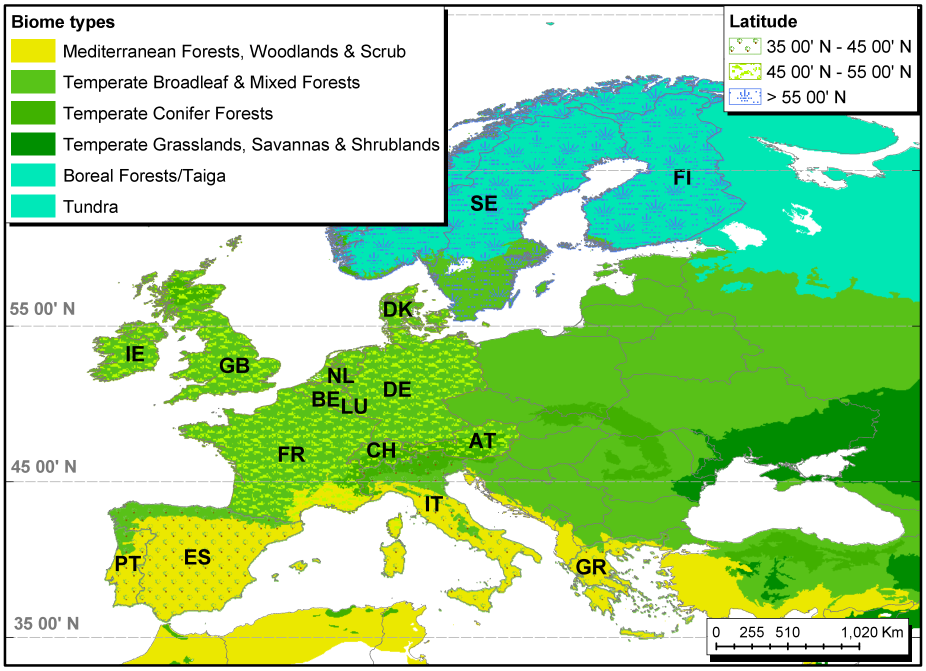

Figure 2. Distribution of terrestrial biomes in Europe and classification of EU-17 countries in latitude categories

For this reason, we divided the 34 European countries into four main geo-climatic clusters, namely (1) Mediterranean Europe[3] (N35-45°); (2) Central Europe[4] (N45-55°); (3) Northern

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[2] Three EFSOS sub-regions are presented in the Annex. Note that in this paper, we exclude the CIS sub-region (i.e. Belarus, Republic of Moldova, Russian Federation and Ukraine) from our study for fear that the vast forest area and the relative low prices of forest products in these countries may bias our valuation result for the whole of Europe.

[3] Greece, Italy, Portugal, Spain, Albania, Bosnia and Herzegovina, Bulgaria, Serbia and Montenegro, Turkey, TFRY Macedonia

[4] Austria, Belgium, France, Germany, Ireland, Luxembourg, Netherlands, Switzerland, Croatia, Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia

Europe[5] (N55-65°), and (4) Scandinavian Europe[6] (N65-71°), corresponding to predominated forest biomes of the region, respectively. Forests in the Mediterranean Europe count for 30% of the total forest cover in Europe, predominated by coniferous and broadleaved evergreen forests (appeared as Mediterranean forest in the paper). The Central and Northern Europe are home to most of the temperate forests, and the total forests areas of the two regions take up 35% and 19% of the forest coverage in Europe, respectively. Finally, forests in the Scandinavian Europe are mainly boreal, accounting for the remaining 16% of European forests. The proposed geo-climatic classification of forest ecosystems will enable a comprehensive understanding of the dynamics of different forests in European countries and allows for sensibility analysis of different tree species in response to climate change. The reasons are the following.

First, latitude specific climate conditions can lead to species diversity and dynamics of forest ecosystems varying considerably across Europe, as reflected in the numbers and composition of tree species. Changing climate will therefore have significant biological and economic impacts at regional scales. The Ministerial Conference on the Protection of Forests in Europe (MCPFE) reported that in Europe about 70% of the forests are currently dominated by mixed forests consisting of two or several tree species and the rest 30% are dominated by one tree species alone, mainly by conifers (MCPFE, 2007). Despite the large existence of uncertainties about future climate conditions, climate change will likely shift forest ecosystem distribution across much of Europe causing changes in the composition of forest tree species and result in significant socio-economic effects by influencing e.g. long-term forest productivity and scenic and spiritual value of natural forests in many European countries, where forest ecosystems are important natural resources to sustain local and national economic development.

Second, the sensibilities of tree species in response to changes of temperature are considered by studying the specific forest types located in different geo-climatic regions. For instance, in the Mediterranean region, most forests consist of sclerophyllous and some deciduous species that have adapted to summer soil water deficit. Temperature changes may allow for an expansion of some thermophilous tree species (e.g. quercus pyrenaica) when water availability is sufficient (IPCC, 2001). Similarly, Garcia-Gonzalo et al. (2007) found that in Scandinavian Europe, the growth of boreal forests is currently limited by a short growing season, low summer temperature and short supply of nitrogen, whereas, the changing climate can increase forest productivity and also carbon stock in the forest ecosystem. This is because an increase in temperature can prolong

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[5] Denmark, United Kingdom, Estonia, Latvia, Lithuania

[6] Finland, Iceland, Norway, Sweden

the growing season, enhance decomposition of soil organic matter, and thus, increase the supply of nitrogen. In turn, these changes may have positive impacts on forest growth, timber yield and the accumulation of carbon in the boreal forests at higher latitudes (Melillo et al. 1993; Lloyd and Taylor 1994; Giardian and Ryan 2000; Jarvis and Linder 2000; Luo et al. 2001; Strömgren 2001).

To summarize, classifying countries and their respective forest biomes by geo-climatic regions has two main advantages. First, the proposed geo-climatic classification will allow us to examine the degree of sensitivity of different forest biomes of each region in response to climate change, as reflected in rising temperature and precipitation rate. Second, forest biomes in one geo-climatic region share similar ecological characteristics, e.g. the composition of tree species, which determines the type of, as well as the quantity and quality of the ecosystem services provided. Therefore, one may expect forest ecosystem services contribute differently to the local livelihoods across geo-climatic regions. This information will be of particular importance in terms of testing the potential of scaling-up total economic values (TEV) of forest ecosystems located in the same geo-climatic region. Furthermore, by comparing the regional TEV of forest ecosystem, our study therefore can shed light on the identification of winners and losers (e.g. countries or regions) of the climate change impacts in Europe and help improving the efficiency of current policy mechanisms by reallocating resources among different groups of people.

2.3 Projecting the Future Changes of Forest Ecosystem Goods and Services due to Climate Change

2.3.1 Classification of Forest Ecosystem Goods and Services (EGS)

Forest EGS are classified following a MA approach (MA, 2003), which provides a practical, tractable, and sufficiently flexible classification for categorizing the various types of EGS, including *provisioning, regulating, cultural and supporting services*. The MA classification with examples of forest EGS is presented in Table 2. In this paper, all observed biophysical data for all EGS[7] are extracted from the FAOSTAT-Forestry database for a reference year 2005 at country level and then summed up on a geo-climatic region scale. Moreover, the quantification of regulating and cultural services is assumed linearly related to the extent of forest area.

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[7] The data report from FAOSTAT does not provide sufficient data on non-wood forest products, for this reason, our figures on the forest provisioning services will not embed this provisioning service. We acknowledge that our estimation is underestimated compared to other studies (e.g. Merlo and Croitoru, 2005) in the literature, as it is more difficult to estimate the provision of non-wood forest products under climate change secenarios.

Provisioning Services

Forest provisioning services are classified into two main categories: wood forest products[8] (WFPs) and non-wood forest products[9] (NWFPs), as suggested by the Food and Agriculture Organization (FAO) of the United Nations (FAO 1999). WFPs refer to seven product categories (as identified in FAOSTAT) representing different industrial sectors: industrial roundwood, wood pulp, recovered paper, sawnwood, wood-based panels, paper and paper board, and wood fuel. NWFPs are broadly defined as "all goods of biological origin, as well as services, derived from forest or any land under similar use, and exclude wood in all its forms (FAO, 1999)". However, NWFPs are excluded from the present valuation exercise for two reasons: (1) Reliable data on NWFPs are difficult to obtain as they are not properly documented and only a few countries systematically monitor production and trade of their most important NWFP. (2) It is very difficult to project the quantitative changes of EGS under future climate scenarios as their productivity are largely affected by the local/national forestry management practices rather than climate change induced reduction of productivity. Thus our estimation of the provisioning value of European forests is lower than those of other studies (e.g. Merlo and Croitoru, 2005).

Regulating Services

As far as regulating services are concerned, two types of ecosystem services provided by European forests are of particular importance: (1) climate regulation (i.e. carbon sequestration) and (2) water and erosion regulation (i.e. watershed protection). It is important to note that this paper focuses on the carbon service alone for two reasons. The first is due to lack of data at a European scale. The second is because the literature that studies the role of forest ecosystems in mitigating climate change has been mainly focused on carbon storage function of forests more than on the watershed protection function. We are aware that excluding the watershed benefits will lead to a lower value estimate of the regulating services provided by forests, thus further studies are needed to advance our knowledge on watershed protection function in forests and their respective values in the context of climate change.

Cultural Services

In Europe, forests provide important cultural services that consist of both recreational and passive use of forests to many countries. In particular, recreational services, including hunting,

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[8] WFPs include industrial wood, wood fuel, small woods and other manufactured wood products.

[9] NWFPs including food and food additives (e.g. fruits, nuts, mushrooms, herbs), fibres (raw material for utensils and construction), resins, plant and animal products used as medicinal or cosmetics, can be gathered from the wild or produced in forest plantations.

natural park visiting, forest landscape and other spiritual uses, represent the most important value in this service category (MCPFE 2007). To avoid double counting, only non-consumptive recreational use of forests[10] is considered here. And passive use of forests is considered for their important inter-temporal implications in the study of climate change impacts. Notwithstanding some of the existing literature in general equilibrium modelling has made some considerable efforts to analyze the climate-driven changes in tourism demands (Berrittella *et al.*, 2006; Bigano *et al.*, 2008), it should be noted that the direct linkage of cultural services with climate change is rather too complex to convey. Rather, we project the changes of forest areas designed for recreational and protective purposes[11] in the context of climate change, and establish a linear relationship between land-use changes and the resultant provision of cultural services.

Table 2. Adapted MA approach for forest EGS classification

Types of Forest EGS		Examples	Explanation of the data uses
Supporting Services	Provisioning Services	Industrial Roundwood, Wood pulp, recovered paper, sawnwood, wood-based panels, paper and paper board, and wood fuel	The data report from FAOSTAT does not provide sufficient data on non-wood forest products, for this reason, our figures on the forest provisioning services will not embed this service type. We acknowledge that our estimation is underestimated compared to other studies (e.g. Merlo and Croitoru, 2005) in the literature, as it is more difficult to estimate the provision of non-wood forest products under climate change scenarios.
	Regulating Services	Climate regulation, i.e. carbon sequestration	We focus only on the carbon sequestration other than watershed protection due to the limited studies for watershed protection in the climate change context. This caveat leaves the value of regulating services underestimated in this study.
	Cultural Services	Recreation and passive use of forest	As for cultural services, both recreational and passive uses of forests in Europe are considered. Note that our analysis is limited to the non-consumptive recreation, such as the enjoyment derived from hunting activities and forest landscape. And passive use of for

Source: adapted from MA (2003)

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[10] The recreational value of forests usually involves both consumptive (e.g. consumption of animal meat) and non-consumptive (e.g. enjoyment derived from hunting activities and forest landscape) uses of forests and can be presented in different forms, such as entry fees to natural parks, travel costs for obtaining leisure enjoyment in the forests, and willingness to pay for enjoying the scenic value of forest, etc.

[11] The designed function of forests is reported by the Global Forest Resources Assessment 2005 (FRA, 2005),

Supporting Services

With respect to the supporting services, indicators for measuring the respective forest ecosystem changes in response to climate change are not well developed and thus, quantity data to measure them are not readily available (MA, 2005). For this reason, we will not tackle this service category directly. It is, however, important to realize that the value of supporting services is embedded in the value of other three MA ecosystem services, in terms of sustaining the healthy ecosystem functioning and the capability of delivering ecosystem services to human society.

All relevant biophysical data, including forest area and quantity of breakdown ecosystem services are collected year 2005, a baseline year since when we built projections of ecosystem goods and services provided by forest ecosystem in any future climate change scenarios.

2.3.2 Projecting the Bio-physical Flows of EGS under Future IPCC Storylines

In order to project the quantitative changes of forest areas and wood products due to climate change, we adopted the simulation results derived from the Advanced Terrestrial Ecosystem Analysis and Modelling (ATEAM) project. This project, which was funded by the 5th Framework Programme of the European Commission with a specific emphasis on assessing the vulnerability of human sectors relying on ecosystem services with respect to global change (Schröter D. et al. 2004), delivers projections in forest areas, wood products and carbon sequestration by forests across the four IPCC storylines for the EU-17. In this project, we extend the projections to the other remaining European countries under consideration exploring the use IMAGE 2.2 (IMAGE 2001). As in ATEAM and the IPCC scenarios, these projection are anchored to the year 2050 and refer to forest areas, wood products and forest carbon sequestration services. These will be discussed in detail in following paragraphs.

Forest areas

Our computation shows that the impacts of climate change on forest land-use vary significantly across latitudes. In the A1FI and A2 scenarios, forest areas decrease, on average, by about 21% and 9% by the year 2050, respectively - see Table A1a in Appendix for more details. The A1FI scenario shows the largest impact due to the no-migration assumption and most severe climate change, with Δ temperature (C°) equal to 4.4 degrees (Thuiller *et al.*, 2005). Both B1 and B2 scenarios present an increase in forest areas, of about 6% for the former and 10% for the latter. The higher increase rate of forest areas in the B2 scenario highlights major change due to the afforestation hypothesis which is also associated with the higher levels of precipitation in this same scenario (Schöter *et al.*, 2005). In particular, Mediterranean Europe is facing a general, negative forest growth in scenario A1FI and A2, but a significant expansion in scenario B1 and B2. Central-Northern and Northern Europe regions present negative growth only in the A1FI scenario, in correspondence with the more severe climatic conditions. In addition, the A2 shows that for the Scandinavian Europe there is a reduction of the forest area. Finally, we have also looked into forest areas specifically designated for recreational use(recreational areas) and for conservation use (wilderness areas), which corresponds to 7.8% and 10.2%, respectively of the forest total area – see Table A1b in Appendix for more details. As we shall see, this data will be of crucial relevance when computing the economic value of cultural services, including recreation and passive use values provided by forest ecosystems.

Wood forest products

As previously mentioned, we consider the assessment of the climate impact on the bio-physical levels of production of the wood forest products under consideration – see Tables A2a to A2g in Appendix for detailed projection results. Given different socio-economic and climatic assumptions for the IPCC storylines (as listed in Table 4), the projection of the quantitative changes of wood forest products varies across different IPCC scenarios over the next 50 years. Putting all these tables together, it is easy to find that the impacts of climate change are unevenly distributed across European forests, depending on the regions where the forests are located, the types of forest products, as well as the scenarios in which either socio-economic or environmental policy is the focus.

All in all, our results do show some significant trends of climate change impacts on the classified regions. For instance, the productivity of most of the wood products in Mediterranean and Scandinavian Europe will be negatively affected by climate change, but the magnitudes of the impacts are subject to the assumptions of climate policies. However, by comparing the quantitative assessment results among the four scenarios, there might be a policy option which can mitigate the climate change impact through forest ecosystems in these two regions under the B-type scenarios. For some of the forest products, we may observe some slightly positive impacts of climate change in Mediterranean Europe. Moreover, with respect to the countries located in both Central and Northern Europe, whether climate change brings positive or negative impacts to the region is even more ambiguous to predict. Generally speaking, the production of most of the forest products will be increased in A2 and B2 scenarios as a result of the joint effects of both climate change and socio-economic changes in the future. In other words, climatic influence may, in part, affect the natural growth rate of forests in those two regions, but the existence of policies may also play an important role in terms of their influence on the land use pattern.

Carbon Storage

The carbon cycle connects forests to climate change as total carbon stored in forests has a very important role in determining the climate stabilization paths. As a matter of fact, the quantity of carbon stocked in tree biomass corresponds to approximately 77% of the carbon contained in the global vegetation, while forest soil stores 42% of the global 1m top soil carbon (Bolin et al., 2000). Forests exchange large quantities of carbon in photosynthesis and respiration, they contribute to the global carbon cycle becoming a source of carbon when they are disturbed, and sink when recovering and regrowing after disturbances. In turn, climate change may also influence the forest ecosystems' capacity of storing carbon dioxide in the future. Against this background, we construct projections for carbon sequestration in forests for all the European countries across the four IPCC storylines – see Table A3 in Appendix for more details. Our findings show that the average carbon stock tends to increase in all scenarios, but the respective magnitudes are different. For instance, in the A1FI scenario, which represents a world orientated towards 'global economic' growth, but with the highest CO_2 concentration and temperature, the total carbon sequestrated by forests appeared to be the lowest compared to other three scenarios. This result is consistent with the findings reported by Schröter et al. (2005), who highlighted that for most ecosystem services the A1FI produces the strongest negative impacts. On the other hand, B-type storylines, which are sustainable development oriented, contribute to an increase in forest areas and consequently, to a large quantity of carbon stock. These figures will be at the basis for the economic valuation exercise that is proposed and discussed in detail in the following section.

2.4 Economic Valuation of European Forest Ecosystems in the Context of Climate Change

2.4.1 A Hybrid Economic Valuation Approach

Following our *hybrid economic valuation model* framework – presented in Figure 3 below, different economic valuation methods are exercised in the capture of the values of the three types of ecosystem services under consideration.

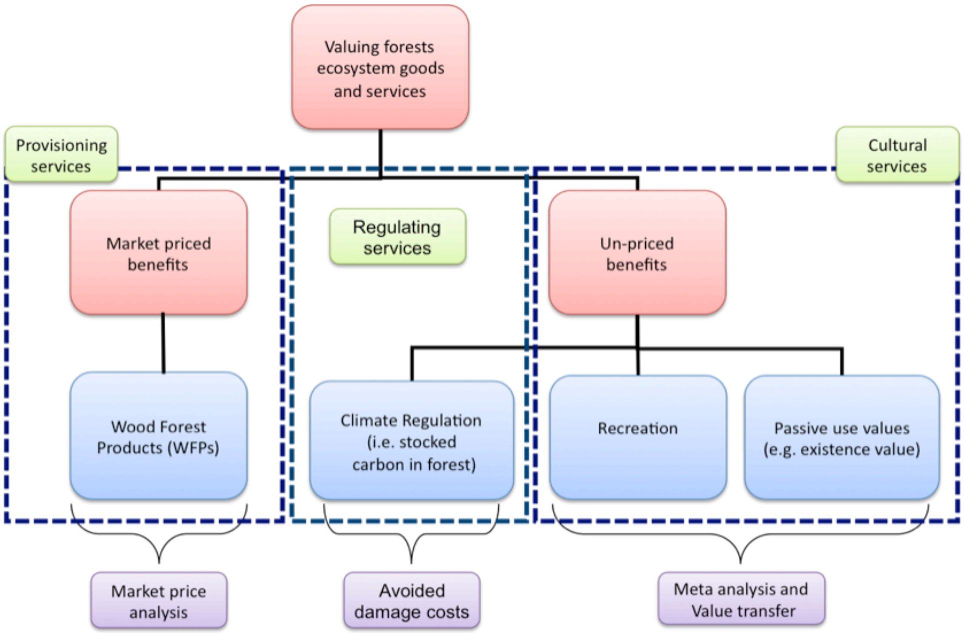

Figure 3: An hybrid economic valuation methodology

First of all, for the provisioning services provided by European forests, we can infer that the economic values are the direct use values obtained from trading wood forest products in the market. Therefore, market prices are used to value this ecosystem service, and this information is derived from FAO database[12] on forests. Secondly, in order to evaluate the welfare changes associated with the carbon regulation, we shall use the avoided damage cost methods that were undertaken by the recent EC funded project, CASES[13] to estimate the marginal damage cost of per additional unit of CO_2 emission. Economic theory tells us that the optimal emission level is determined by the intersection of the marginal damage cost of emissions and the marginal benefit from damage mitigation (or marginal abatement costs). Thus the crossing point corresponds to the unit value of carbon sequestration, which gives rise to the optimal policy to incentivize the necessary abatement in the achievement of the global carbon stabilization goal, and can be used to calculate the total economic value of carbon stored in forests. Finally, with respect to the cultural services, meta-analyses and value transfer methods are jointly used. These two methods are

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[12] http://faostat.fao.org/site/381/default.aspx

[13] CASES stands for “Cost Assessment of Sustainable Energy Systems” for EU countries and the selected non-EU countries, including Turkey, Brazil, India and China. The study aimed at providing a comprehensive and dynamic assessment of the full costs of electricity generation based on the state-of-the art methodologies, taking into account both geographical and temporal extend of the impacts and social economic impacts, such as health and safety, economic production and consumption, recreation, and environmental and natural assets caused by climate change.

anchored in non-market valuation methodologies and rely on the existing databases[14] of non-market valuation studies for forests in Europe. All values are estimated under four IPCC scenarios in 2050 and expressed in 2005 US$. However, the specific nature and availability of data as well as the different valuation procedures embraced for each of the ecosystems services under consideration will merit a separate discussion.

2.4.2 The Economic Value of Wood Forest Products (WFPs)

In the present study, the methodological approach builds up on a two-step estimation process: (i) computation of annual price of WFPs (ii) projections of total values of WFPs to year 2050 under different IPCC scenarios. Finally, projected future value of WFPs will be compared across different future scenarios to estimate the welfare changes due to moving from one scenario to another.

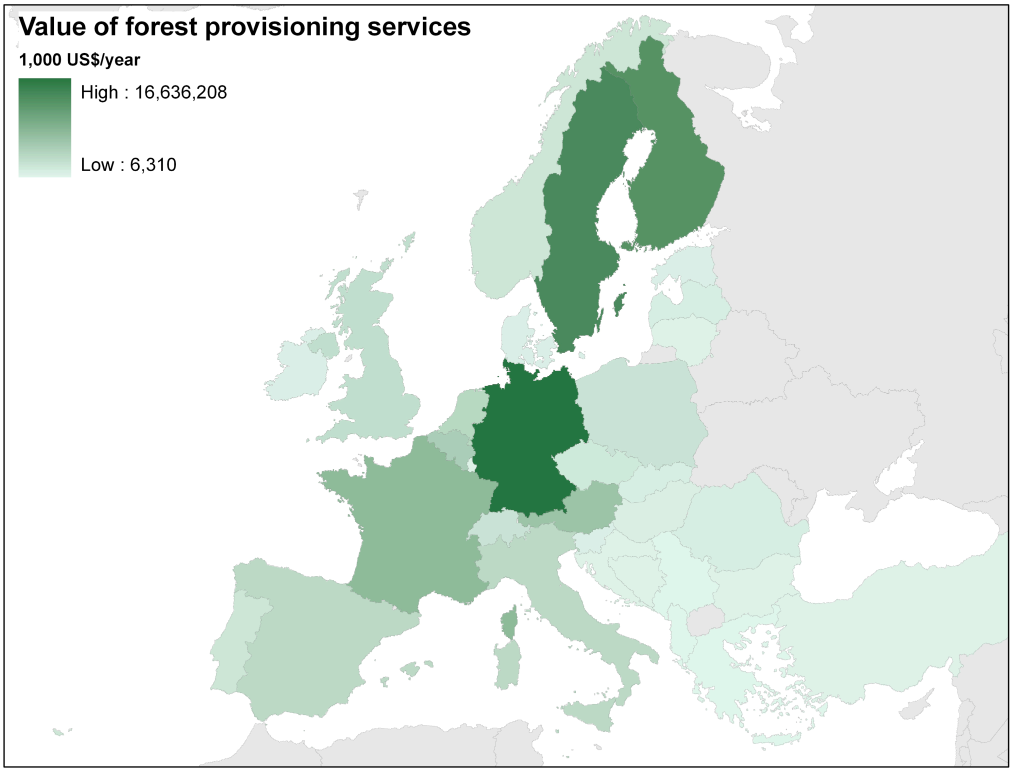

Figure 4. Value of provisioning service in 2005

The first step consists of calculating the total value of all forest products for each country, taking into account export values and export quantities for year 2005, available at country level from

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[14] The popular databases for non-market valuation study include: Environmental Valuation Reference Inventory (EVRI), Envalue, and the Ecosystem Services Database.

FAOSTAT. In the absence of data about consistent prices of WFPs among all countries, we assume that total domestic production of a country's WFPs will be totally exported to abroad consumption. This assumption thus simplifies the question and allows us to estimate approximately market price of each WFP that a country can get from international trade by dividing total export value of the product by the quantity exported. Our results show that Sweden, Norway, Germany and France are the most important WFPs producers in Europe, where the highest value of provisioning services are registered – see Figure 4.

The second step is then to project the total value of WFPs to 2050. Based on the result of a literature survey[15] and observed historical data[16], we assume that that real prices of wood products will remain stable in the next 50 years, while allowing different prices to exist across countries (Clark, 2001; Hoover and Preston, 2006; Bolt et al. 2002). Thus, the projection of total value of each type of WFPs depends only on the total quantity produced by a country under different future scenarios. The computation is expressed by Equation (1).

$$TV_n^S = \sum_{i=1}^{7} \frac{ExportValue_{in}}{ExportQuantity_{in}} \cdot Q_{i,n}^S \qquad \text{with } S = A1FI, A2, B1 \text{ and } B2 \text{ storylines} \tag{1}$$

where *TV* is the total value of WFPs (*i* type of WFP) in Country *n* under IPCC scenario *S*. Furthermore, by aggregating the total values of WFPs at the scale of geo-climatic groupings. Finally, by summing-up values over all of the WFPs commodities and countries located at each geo-climatic region, we can get a regional total value of WFPs for both reference year 2005 and future scenarios by 2050. Results are presented in Table 3.

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[15] Clark (2001) offers a theoretical analysis and an empirical examination of wood prices, based on aggregated global wood market data over the last three decades. Hoover and Preston (2006) analyze trends of Indiana (USA) forest products prices using statistical data from 1957 to 2005. Although different in the spatial scale of the analyses, both papers lead to a similar conclusion: there is no evidence of increase in real prices for wood in the long term. This means that that no global wood shortage is predicted, a result that can be explained by the technological development leading to an increase in resource productivity (less wood required in the production process and enhanced wood supply).

[16] The World Bank time series data providing estimates of the average prices for total produced round wood (Bolt et al. 2002), according to which the trend in real prices remained relatively constant in the 30-years period 1971-2006. The forest net rents of world countries are taken from World Bank database, available online at: http://tahoe-is-walking-on.blogspot.com/2010/01/world-banks-ans-adjusted-net-saving.html.

Table 3. Projection of Total Value of WFPs for European Forests (Million$, 2005)

IPCC scenarios	Mediterranean Europe	Central Europe	Northern Europe	Scandinavian Europe	Total Europe
A1 2050	6,413	41,250	5,413	35,540	88,616
A2 2050	6,453	47,556	7,215	33,943	95,167
B1 2050	8,018	41,441	4,712	31,772	85,943
B2 2050	8,736	48,742	6,810	31,943	96,231

NB: Country-level value projections can be found in Appendix Table A4a-A4g and A5.

Table 4. Projection of Total Productivity Value of WFPs (US$/ha/yr, measured in 2005)

Scenarios	Mediterranean Europe	Central Europe	Northern Europe	Scandinavian Europe
A1 2050	168 (+5.3%)	824 (+0.6%)	749 (+60.8%)	749 (+64.2%)
A2 2050	139 (-12.8%)	777 (-5.1%)	682 (+46.4%)	730 (+60.0%)
B1 2050	134 (-16.1%)	584 (-28.7%)	401 (-13.9%)	668 (+46.4%)
B2 2050	141 (-11.9%)	633 (-22.7%)	503 (+8.0%)	701(+53.6%)

NB: Percentage variation from initial benchmark in 2005 are showed in parentheses.

Furthermore, these values are divided by the forest size located in the same area, and gives rice to productivity values (in $/ha term) of forest biomes in terms of providing WFPs– see Table 4 for the computation results. As we can observe, the WFPs productive values vary among the four geographical groupings as they reflect the different contributions of various forest biomes to the local economy. For example, Mediterranean Europe has a lower sensitivity to climate change in terms of the total productivity value. In other words, the weakest variations in total productivity value of WFPs are registered in Mediterranean Europe, while the highest variations are reported in the Northern and Scandinavian European regions. Moreover, higher productivity values are also found in both economic oriented A-type scenarios.

Finally, we select Scenario A2 as a benchmark for a comparative analysis to estimate the welfare changes across different climate change scenarios. Characterized by a high population, strong economic growth and high income per capita, A2 scenario is today interpreted by the European Commission as the benchmark scenario, so as a reference point in the evaluation of the (comparative) welfare changes due to climate change. The results of this comparison may provide important policy guidance that allows policymakers to understand the magnitude of possible welfare gain/loss in different future state of the world due to their choice of policy options. By comparing the values of WFPs across different future IPCC scenarios, our results shows no unique pattern in terms of welfare gain/loss across regions – see Table 5. However, we do find that a focus on global economic growth as presented by A1 scenario can lead to welfare losses in most European regions, compared to a local economic development scenario A2. Moreover, global sustainable development strategies implemented in B1 scenario will reduce the total value of WFPs in all regions, resulted in a highest welfare loss from all forestry sectors in Europe. This is probably a result of reduced global demand for natural resources due to the improved production efficiency. Finally, regional sustainable developing plans may have significant positive impacts on the Mediterranean region as shown in Scenarios B2. The total economic value of WFPs in the region is projected so high that it can offset the loss in rest of Europe and lead to an average welfare gain in Europe. Thus our result suggest that SFM may be more economically cost-effective in the Mediterranean countries, compared to the Northern and Scandinavian European countries, where SFM has already been well established and effectively implemented.

Table 5. Comparison of Total Value of WFPs for European Forests

Benchmark A2 Scenario		Mediterranean Europe (N35-45)	Central Europe (N45-55)	Northern Europe (N55-65)	Scandinavian Europe (N65-71)	Europe
Absolute value difference (Million$, 2005)	A1vs.A2	-40	-6,306	-1,802	1,597	-6,551
	B1vs.A2	1,565	-6,115	-2,503	-2,171	-9,223
	B2vs.A2	2,283	1,186	-405	-1,999	1,065
Percentage change	A1vs.A2	-0.6%	-13.3%	-25.0%	4.7%	-6.9%
	B1vs.A2	24.3%	-12.9%	-34.7%	-6.4%	-9.7%
	B2vs.A2	35.4%	2.5%	-5.6%	-5.9%	1.1%

2.4.3 The Economic Value of Regulating Services

Forest conservation or the prevention of deforestation in order to stabilize Green House Gas (GHG) emissions – questions not originally included in the Kyoto Protocol – have been officially recognized in COP16 in Cancun in December 2010 as one of the most important options to the post-Kyoto climate policies for combating climate change. The estimation of the economic value of climate regulating services (i.e. carbon storage) provided by forest ecosystem is therefore considered to have a very important impact on policy making for CO_2 stabilization in Europe. We acknowledge that the economic value estimates reported for regulating services in the present paper are underestimated, as we do not undertake a valuation of the other regulating services, e.g.

watershed protection and soil nutrient cycling, due to the limited knowledge about how to quantify those services in physical terms, both with respect to climate change impacts as well as in terms of a projection of the respective future changes. As previously shown that the carbon stocks in forests are projected to increase on average in Europe under all 4 IPCC storylines in the next 50 years, we may therefore expect to obtain some benefits from forest regulating services. However, the magnitudes of those benefits may vary across different forest biomes.

The methodological framework for the valuation of the regulating services consists of two steps: we first compute the marginal value of carbon storage in forests (2005US$/tC), which are then used to estimate the total economic values that can be obtained in different geo-climate regions under the IPCC scenarios.

First of all, the marginal value of carbon storage refers to the benefits from avoided damages[17] caused by incremental CO_2 or CO_2-equivalent GHG emissions in the atmosphere due to the carbon sequestration functions of forest ecosystem. In the present paper, we build our analysis upon an existing project, “Cost Assessment for Sustainable Energy Systems” - CASES[18], a worldwide study funded by the EU.

One of the main features of CASES is that it is built upon the Integrated Assessment Models (IAMs), which by definition combine the dynamics of global economic growth with the dynamics of geophysical climate dynamics, to estimate the cost of GHG emissions under different energy evolution paths in 2020, 2030 and 2050. The existing literature on IAM has been intensively reviewed under the project and various available estimates in the recent years were taken into account in its final value estimates. Among all others, the value of social costs of carbon estimated by the UK’s Department for Environment, Food and Rural Affairs (DEFRA 2005) was adopted, for it reflects the policy context in which the values are used, and it combines the results of a number of IAM’s in a transparent matter. As a consequence, the CASES project was able to obtain three levels of estimates of marginal damage costs, i.e. lower, upper and central estimates[19],

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[17] The avoided damage costs assessment method has been widely used in the literature (see Cline, 1992; Nordhaus, 1993a,b; Merlo&Croitoru, 2005; CASES, 2008) to calculate indirectly the benefits from carbon sequestrated in forests, but it is important to note that the concept is different from the market price of carbon (obtained via emission trading scheme) and the marginal abatement cost (involves the costs of technological R&D for facilitating the emission abatement), although under certain restrictive assumptions the three measures would be broadly equal, at the margin (DEFRA, 2007).

[18] CASES, Project No.518294 SES6, (2006-2008). Project official website: http://www.feem-Project.net/cases/

[19] The values are based on full *Monte Carlo* runs of the *FUND* and *PAGE* models, in which all parameters varied to reflect the uncertainty surrounding the central parameter values in both models. The lower and upper bounds are the 5% and 95% probability values of the *PAGE* model, while the central guidance value is based on the average of the mean values of the *FUND* and *PAGE* models. A declining discount rates is use as suggested by the UK

respectively. For example, as reported in the CASES final report, the lower estimates of marginal damage costs evolve from € 4/tCO_2 in 2000 to € 8/tCO_2 in 2030; the upper estimates evolve from € 53/tCO_2 in 2000 to € 110/tCO_2 in 2030; and the central estimate evolves from € 23/tCO_2 in 2000 to € 41/tCO_2 in 2030.

In the present study, we adopt a value estimate of 96.1 Euro/tC from the CASES report, referring to the central estimate of the avoided cost of 1 ton of carbon in 2080. The value is first adjusted to our paper by discounting to the real Euro value in 2005, using a 3% discount rate, and then converted to 2005US$ taking into account the real exchange rate and the Purchasing Power Parity (PPP). Finally, future economic benefits (measured in 2005 US$) of carbon stocks in each country's forests are calculated by multiplying the US$/tC value by the projected quantity of carbon totally stored in the same forests in 2050 (see section 3), for each of the IPCC storylines, and then aggregated to compute the regional total benefits for the four large geo-climatic groupings.

The results of the valuation are presented in Table 6. These suggest that, in addition to the forest area the predominant tree species may play a significant role in the determination of the carbon sequestration capacity in a geographical region, and therefore on the value of the forest's regulating services. For example, the forests in Central Europe contribute to the largest portion of benefits from the carbon regulating services in Europe. But this does not only depend on the fact that this area occupies the largest forest areas in Europe, but also because the type of forests in this area may have tolerance and capacity in terms of carbon sequestration.

Table 6. Projection of Total Benefits of Carbon Storage in European Forests (Million$, 2005)

Scenarios	Mediterranean Europe	Central Europe	Northern Europe	Scandinavian Europe	Europe
A1 2050	37,176	117,241	11,489	32,817	198,722
A2 2050	45,790	159,453	17,362	32,605	255,210
B1 2050	66,575	190,755	22,679	46,310	326,320
B2 2050	63,609	190,341	23,546	35,733	313,229

In addition, the productivity value of climate regulating services ($/ha) is also calculated based on the projected forest areas under different future scenarios (See Table 7 and/or Appendix-Table 6

Government 'Green Book'. The equity weighting of damages in different regions is applied to aggregate the regional damage costs to global damages, in other words, damages in richer regions receive lower weights and damages in poorer regions receive higher weights.

for disaggregated data). The results show clearly the marginal benefit of carbon regulating services provided by different forestlands. Moreover, different forest management scheme may also influence these values. For instance, *ceteris paribus*, the B1 scenario shows the highest marginal value of regulating services provided by European forests.

Table 7. Projection of the Productivity Value of Carbon Sequestration (US$/ha/yr, 2005)

Scenarios	Mediterranean Europe	Central Europe	Northern Europe	Scandinavian Europe	Europe
A1 2050	927	2,712	1,563	748	927
A2 2050	950	2,795	1,625	763	950
B1 2050	1,093	2,879	1,913	992	1,093
B2 2050	990	2,684	1,720	836	990

To better interpret the results, we undertake a comparative study among all four IPCC scenarios. Table 8 shows the comparative results of three IPCC scenarios (i.e. A1, B1 and B2) with respect to the A2 (BAU) storyline.

Table 8. Projection of Total Benefits of Carbon Storage in European Forests

Benchmark A2 Scenario		Mediterranean Europe	Central-Northern Europe	Northern Europe	Scandinavian Europe	Europe
Absolute value difference (Million$, 2005)	A1vs.A2	-8,614	-42,212	-5,874	212	-56,489
	B1vs.A2	20,785	31,303	5,317	13,705	71,109
	B2vs.A2	17,819	30,888	6,183	3,128	58,018
Percentage Change	A1vs.A2	-18.8%	-26.5%	-33.8%	0.6%	-22.1%
	B1vs.A2	45.4%	19.6%	30.6%	42.0%	27.9%
	B2vs.A2	38.9%	19.4%	35.6%	9.6%	22.7%

From these results, one can clearly see that the countries within Mediterranean Europe (Greece, Italy, Portugal, Spain, Albania, Bosnia and Herzegovina, Bulgaria, Serbia and Montenegro, Turkey and Yugoslav) will benefit from the highest welfare gain in a movement towards the B1 or B2 storyline. In fact, this geo-climatic zone can experience welfare gains with increases in the value of the carbon sequestration services of up to 45%. In other words, the "no adoption" of a B2 storyline, and a movement towards an A2 scenario, will be associated with a high welfare loss in Mediterranean Europe due to the reduced quantity and quality of the forest ecosystem services under consideration.

Alternatively, moving from an A2 towards an A1 scenario will always involve a welfare loss for Mediterranean Europe. In short, for Mediterranean Europe the 'A' scenarios will always be associated with reduced quantity and quality of forest ecosystem services and the resultant lowering of human welfare levels. On the other hand, storyline B1 is ranked as the most preferred scenario for this geo-climatic area. The region of Scandinavian Europe (including Finland, Norway and Sweden) presents mixed results. Firstly, moving from an A2 towards an A1 scenario will not involve any welfare loss; on the contrary small welfare gains can be registered. Furthermore, in a movement towards a B type scenario, Scandinavian Europe will also experience significant welfare gains in the provision of carbon sequestration services. The respective welfare gains are, however, much lower when compared to Mediterranean Europe, *ceteris paribus*. If we consider Mediterranean and Scandinavian Europe as two 'corner situations' in terms of the respective welfare change magnitudes, we can observe that Central Europe and Northern Europe each present an intermediate state of affairs. In any case, it is important to note that a movement from an A2 to an A1 scenario will be always associated with high welfare losses in regulating services, with the highest losses registered among the Northern Europe countries (Denmark, United Kingdom, Estonia, Latvia and Lithuania). Finally, both Central Europe and Northern Europe show a similar profile in terms of carbon sequestration values: any B type scenario is characterized by a welfare gain, results that are in accordance with what is also registered in Mediterranean and Scandinavian Europe.

2.4.4 The Economic Value of Cultural Services

The cultural services provided by forest ecosystems consist of two components in our analysis: recreational use (e.g. nature-based *tourism* in forests) and passive use (e.g. existence and bequest value of forests and biodiversity). Not being traded in regular markets, the values of recreational and passive use of forests are usually measured as willingness to pay (WTP) figures using non-market valuation approaches (namely: travel cost method, contingent valuation and choice experiments). According to previous literature reviews on cultural values, an expected utility specification can be used to describe how individuals are willing to trade income for increases or decreases in forest cultural services, under the assumption that the estimated marginal value of the service decrease with an increase in the area size of the forest site, and increases with an increase of the income level of the country where the forest is located (e.g. Hammitt, 2000; Markandya *et al*., 2008; Chiabai *et al*. forthcoming) The driving force of changes in future forest areas is considered to be climate change in this paper, therefore, the expressed WTP estimate for trading-off the forest resources also reflects the fact that the individual's preference to enjoy a certain kind of culture service may shift from one forest to another driven by the change in future climate conditions.

Due to the large scale of our study, it is impossible to conduct new original studies for all 34 countries under consideration. Therefore, a meta-analysis based value transfer method is used to estimate the cultural value of forests situated in each geo-climatic region. Future changes of these values driven by climate change are projected according to the change in forest areas, in GDP and population under different IPCC storylines. The change in demand for recreation in forests, driven by climate change is not considered in the present analysis due to the lack of information and relevant studies in the literature. This leaves us with a focus on the valuation of the2005$/ha average WTP estimates (expressed in 2005$/ha) for obtaining cultural services (either recreational use or passive use) from forests in each geo-climatic region.

For each region, we assume that one major forest biome can be identified as a representative forest type which survives the local climate. The main advantage of this type of assumption is that we can select a few original non-market valuation studies that have been conducted in any one country located in the same geo-climate region to undertake the value transfer within the same region.

The meta-analysis enables us to explain the variance of the available WTPs (Willingness-To-Pay) as a function of a few statistically significant explanatory variables[20]. In particular, the main explanatory factors for forest recreation and passive use are the forest size designated to recreation or to biodiversity conservation (S), and the income level of the study area (I, measured as PPPGDP), according to the following model:

$$(2) \qquad \log V = \alpha + \beta \log S + \gamma \log I$$

where V is the marginal value of a given forest site designated to recreation or conservation of biodiversity,

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[20] A similar approach is used by the authors in another recent research project (COPI) concerning a worldwide valuation of forest ecosystems in the context of policy inaction rather than climate change (see Markandya et al. 2008 for more details).

By running regression (2), we can estimate the marginal effect on V of the forest size (β) and the income level of the country where the site is located (γ). The WTP figures included in the regression are selected from an extensive literature review process focusing on a number of valuable studies carried out in Europe.

Table 9. Results of the meta-regression function for recreational and passive use values

Dependent variable	***Recreation use***		***Passive use***	
	Coefficient (std.error)	T-value	Coefficient (std.error)	T-value
LogWTP				
Explanatory factors:				
constant	3.274 (3.698)	0.89	3. 972 (2.835)	1.40
LogSIZE	-0.445 (0.073)	-6.14	-0.603 (0.079)	-7.58
LogINCOME	0.599 (0.352)	1.70	0.889 (0.255)	3.49
Nobs	59		23	
R^2	0.452		0.797	
Adj R^2	0.433		0.797	

The results of the meta-analyses confirm our expectations both for forest recreation and passive use values: income level and size of forest areas are the main, statistically significant factors explaining variation in WTP estimates for changes in forest cultural services (See Table 9). The β coefficient on forest recreation size (logSIZE) is negative and significant for both recreation and passive use, showing that the marginal value of these services decreases with a marginal increase in forest area. The coefficient on income γ (logINCOME) is positive and significant, revealing a negative correlation of marginal values and income. The coefficients on passive use values are higher compared to those of recreation, showing a higher sensitivity of forest size and income on marginal values.

The estimated coefficients from the meta-analysis are then used for the geographical value transfer (in different geo-climate regions) as well as for the inter-temporal value-transfer under different IPCC scenarios.

For the geographical value transfer, a few representative studies are selected in each European geo-climate region (Table 10 and 11) The WTP figures selected from these studies[21] are scaled up

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[21] When several representative case studies and values are available, the mean marginal value is used.

to the corresponding higher geo-climatic region and forest biome, by taking into account the effect of the size of the forest area under valuation, β, according to the following formula:

$$(3) \qquad V_{EU,l} = V_{i,l}\left(\frac{S_{i,l}}{S_{EU,l}}\right)^{\beta}$$

where

$V_{EU,l}$ is the estimated WTP/ha for Europe by geo-climatic region l, $V_{i,l}$ is theWTP/ha of country i by geo-climatic l (from representative case studies), $S_{i,l}$ is the forest area designated to recreation or conservation in country i by geo-climatic region l, and $S_{EU,l}$ is the forest area designated to recreation or conservation in Europe by geo-climatic region l

Data on forest areas designated to recreation and biodiversity conservation by country are taken from FAO/FRA 2005. For the inter-temporal value transfer, the estimated marginal values in 2005 are projected to 2050 using population and PPPGDP growth rates, and by taking into account the effect of forest size[22], under different IPCC scenario, as illustrated below:

$$(4) \qquad V_{i,T_1} = V_{i,T_0}\left(\frac{H_{i,T_1}}{H_{i,T_0}}\right)\left(\frac{S_{i,T_0}}{S_{i,T_1}}\right)^{\beta}\left(\frac{PPPGDP_{i,T_1}}{PPPGDP_{i,T_0}}\right)^{\gamma}$$

where:

$V_{i,T1}$ is the estimated value/ha/year for country i in year T,
$V^*_{i,00}$ is the estimated value/ha/year for country i in year T_0, T_1 is year 2050, while T_0 is the baseline year 2005.

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[22] We assume no variation over time in the percentage of forest area designated to recreation or conservation.

Table 10. Selected studies on recreational use for geographical value-transfer

Country	Reference study	Forest biome	Geo-climatic region
United Kingdom	Scarpa, R., S. M. Chilton, W. G. Hutchinson, J. Buongiorno (2000)	Temperate broadleaf and mixed forests	Northern Europe
The Netherlands	Scarpa, R., S. M. Chilton, W. G. Hutchinson, J. Buongiorno (2000)	Temperate broadleaf and mixed forests	Central-Northern Europe
Finland	Bostedt, G. and L. Mattsson (2005)	Boreal	Scandinavian Europe
Italy	Bellu, L. G. and Cistulli V. (1994)	Mediterranean and Temperate Broadleaf	Mediterranean Europe

Table 11. Selected studies on passive use for geographical value-transfer

Country	Reference study	Forest biome	Geo-climatic region
United Kingdom	Garrod, G.D. and Willis, K. G. (1997) Hanley, N., Willis, K, Powe, N, Anderson, M. (2002) ERM Report to UK Forestry Commission (1996)	Temperate	Northern and central-northern Europe
Finland	Kniivila, M., Ovaskainen, V. and Saastamoinen, O. (2002) Siikamaki, Juha (2007)	Boreal	Scandinavian Europe
Spain	Mogas, J., Riera, P. and Bennett, J. (2006)	Mediterranean	Mediterranean Europe

Finally, by multiplying the WTP estimates V(\$/ha) for recreational or passive use of forests with the sizes of forest area S that have been designated for recreation or conservation following the different climate change scenarios (See Appendix-Table 10 for the computation results), we can obtain the total recreational or passive use value for each region under each IPCC storyline. For each individual IPCC storyline, the total cultural value of a geo-climatic region is the sum of the respective recreational and passive use value of the forests.

Final results on cultural services show that marginal values may widely differ according to the latitude (or geo-climatic region) where the forest is located (see Table 12 and 13) For recreational values, the highest estimates can be seen in Northern Europe followed by Central-Northern

Europe, probably due to the facilities provided for forest recreation in these countries. The lowest values are registered in the Scandinavian countries. For passive use values, instead, the highest estimates are registered in the Mediterranean countries, which have a higher potential for biodiversity and ecosystem conservation. With regards to the projected total cultural economic values, Mediterranean Europe appears to have the highest values, followed by Central and Scandinavian Europe (see Table 14) Within the same geo-climatic region, climate change might have a different impact on the cultural services provided in the local economy. By comparing the different IPCC scenarios, we can see that total values are generally higher for B1 and B2 scenarios which are environmentally oriented than for the economically oriented scenarios (A1 and A2).

Table 12. Projections of marginal recreational values of European forests (US$/ha/yr, 2005).

Scenarios	Mediterranean Europe	Central-Northern Europe	Northern Europe	Scandinavian Europe
Initial 2000	1.06-3.06	0.43-2.61	1.88-7.10	0.16-1.05
A1 2050	1.25-7.87	1.07-8.15	4.17-99.92	0.23-0.53
A2 2050	1.26-7.91	0.68-5.17	4.03-96.55	0.23-0.54
B1 2050	1.20-9.24	0.81-8.08	3.97-124.34	0.27-0.73
B2 2050	1.03-6.77	0.65-4.83	2.97-62.55	0.22-0.44

Table 13. Projections of marginal passive use values of European forests (US$/ha/yr, 2005).

Scenarios	Mediterranean Europe	Northern and Central-Northern Europe	Scandinavian Europe
Initial 2000	356-615	123-182	123-255
A1 2050	898-1,552	361-534	219-454
A2 2050	902-1,558	344-509	220-457
B1 2050	748-1,292	342-506	262-543
B2 2050	678-1,171	230-340	203-421

Table 14. Projection of Cultural Values of European Forest Ecosystem (Million$, 2005)

Scenarios	Mediterranean Europe	Central Europe	Northern Europe	Scandinavian Europe	Europe
A1 2050	3,988	2,123	305	1,204	7,620
A2 2050	4,850	2,475	425	1,185	8,936
B1 2050	9,006	4,270	818	2,993	17,088
B2 2050	8,457	3,108	608	2,223	14,396

Finally, we compare the total values of forest cultural services among the different IPCC scenarios, using scenario A2 as a benchmark for the analysis (Table 15). This scenario is characterized by the largest population and the highest GDP per capita. By comparing the remaining scenarios with the benchmark, we can capture the costs associated with a change from one scenario to another, and from environmentally oriented scenarios towards economically oriented scenarios.

Table 15. Comparison of Total Value of Cultural Values for European Forests

Benchmark A2 Scenario		Mediterranean Europe (N35-45)	Central Europe (N45-55)	Northern Europe (N55-65)	Scandinavian Europe (N65-71)	Europe
Absolute value difference (Million$, 2005)	A1vs.A2	-862	-352	-121	18	-1,317
	B1vs.A2	4,156	1,795	393	1,808	8,152
	B2vs.A2	3,607	633	182	1,038	5,460
Change in %	A1vs.A2	-17.8%	-14.2%	-28.3%	1.5%	-14.7%
	B1vs.A2	85.7%	72.5%	92.3%	152.5%	91.2%
	B2vs.A2	74.4%	25.6%	42.9%	87.5%	61.1%

Our comparative analysis of IPCC scenarios shows results which are consistent with our previous findings. For instance, as far as biodiversity and ecosystem conservation are concerned, the A1 scenario is worse off when comparing it to the A2 scenarios, a conflicting result compared to those obtained for the provisioning service. This could be due to the harvesting of the forest resources for WFPs production which may result in a reduction of forests available for other uses, such as recreational or educational uses. On the contrary, in all B-type scenarios climate change has positive impacts on the social economy as the management efforts in sustainable development and environmental production may halt or compensate the negative impacts of climate change. This finding, therefore, suggests that moving from the B-type scenarios to an A2 scenario will involve costs of policy inaction, as the economic oriented policy may reduce the welfare gain from forest cultural services, such as the enjoyment of natural environment and the knowledge of the existence of biodiversity in the forests.

2.5 Conclusions

This paper reports on an original economic valuation of climate change impacts on forest ecosystem goods and services, and biodiversity. On the one hand, we provide a comprehensive classification and mapping of the different European countries according to their contribution in the supply of forest goods and services. The proposed analysis is anchored to the well-known classification proposed by the MA Approach. On the other hand, we investigate the role of each country in detail, providing forest provisioning services, regulating services and cultural services.

In order to value the climate change impacts, we first identified four different climate scenarios, which we refer to as the A1FI, A2, B1 and B2 scenarios, corresponding to the four IPCC storylines, and evaluated here to the year 2050. Secondly, we proceed with the analysis and evaluation of climate change impacts on the total forest area (for each country), as well as, on the provisioning quantities (in bio-physical terms) across all forest goods and services under consideration. The projections of future trends of forest areas and the provision of wood forest products in 2050, in terms of four IPCC storylines, were constructed using global climate models, including HadCM3, and simulating the response of the global climate system to increase greenhouse gas concentrations. Moreover, considerable impacts of differentiated latitudes on the variability of forest EGS were taken into account by carefully regrouping the 34 selected countries located in different latitude intervals. As a consequence, it not only enabled us to identify the respective forest productivity related to predominant forest types situated in each latitude interval, but also to assess and compare the sensitivity of the differentiated forest types in response to climate change impacts. Both of these aspects have been considered when projecting the future trends of forest area and forest product flows by 2050, in terms of the four IPCC storylines – see Table A7 in the Appendix for a summary of the results. Finally, we applied various economic valuation methods (including market and non-market valuation methods, primary and value transfers methods) to estimate the values of the three MA service categories involved, i.e. the provisioning services, regulating services and cultural services provided by European forests.

Figure 5 - 7 summarize the economic valuation results from three different types of ecosystem goods and services provided by forest ecosystems in Europe across four IPCC scenarios. As shown, B scenarios are associated with the highest levels of provision in all of the ecosystem services under consideration, i.e. wood products, carbon sequestration and cultural services. First, as regards provisioning services, we can see that the total value of WFPs ranges between 41.2 and 47.5 billion dollars for Central Europe to 5.4 and 7.2 billion dollars in the Northern Europe, respectively in the A1 and A2 scenarios. For this service, Mediterranean Europe provides a relatively weak role in provision with values ranging from 6.4 billion dollars in the A1 scenario to 8.7 billion dollars in B2. Moreover, as far as the carbon sequestration services are concerned, we can see that the stock of carbon stored in the European regions varies from 37.2 to 45.8 billion dollars in the Mediterranean countries, respectively, in both the A1 and A2 scenarios and to 63.6

billion in the B2 scenario and 66.6 billion in the B1 scenario. Therefore, the B1 scenario is ranked as the one with the highest level of provision. The same ranking holds for the Central-North and Northern European regions, where the B1 scenario is associated with the provision of 190.3 and 23.5 billion dollars, respectively. Finally, for the Scandinavian group of countries, B1 is ranked with the highest level of provision of carbon sequestration services, amounting to 46.3 billion dollars. Finally, our results show that cultural services provided by forest ecosystems have their highest levels in the Mediterranean countries, ranging from 8.4 to 9.0 billion dollars, respectively, in the B2 and B1 scenarios, to 3.9 to 4.8 billion dollars, in the A1 and A2 scenarios. For the Scandinavian group of countries, B1 is also ranked with the highest level of provision of cultural services, but now amounting to 2.9 billion dollars, followed by the B2 scenario, which is tagged with a total cultural value of 2.2 billion dollars. In short, we can conclude that the magnitude of the values of forest ecosystem goods and services varies according to the nature of service under consideration, with carbon sequestration ranked as the most valuable service.

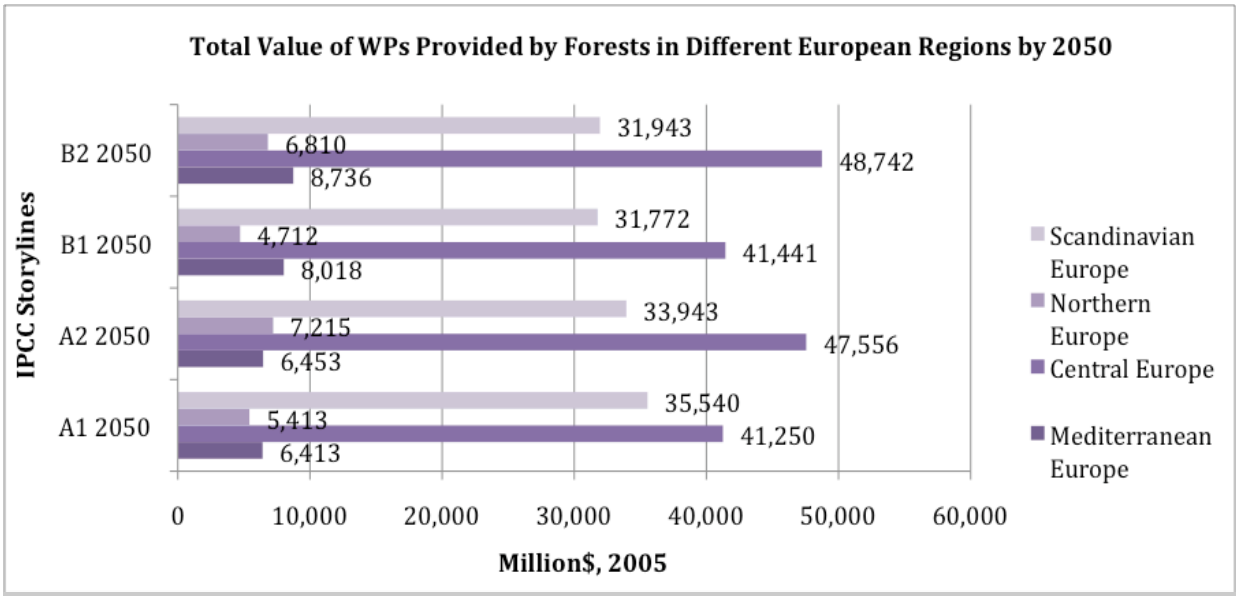

Figure 5. Forest wood products value

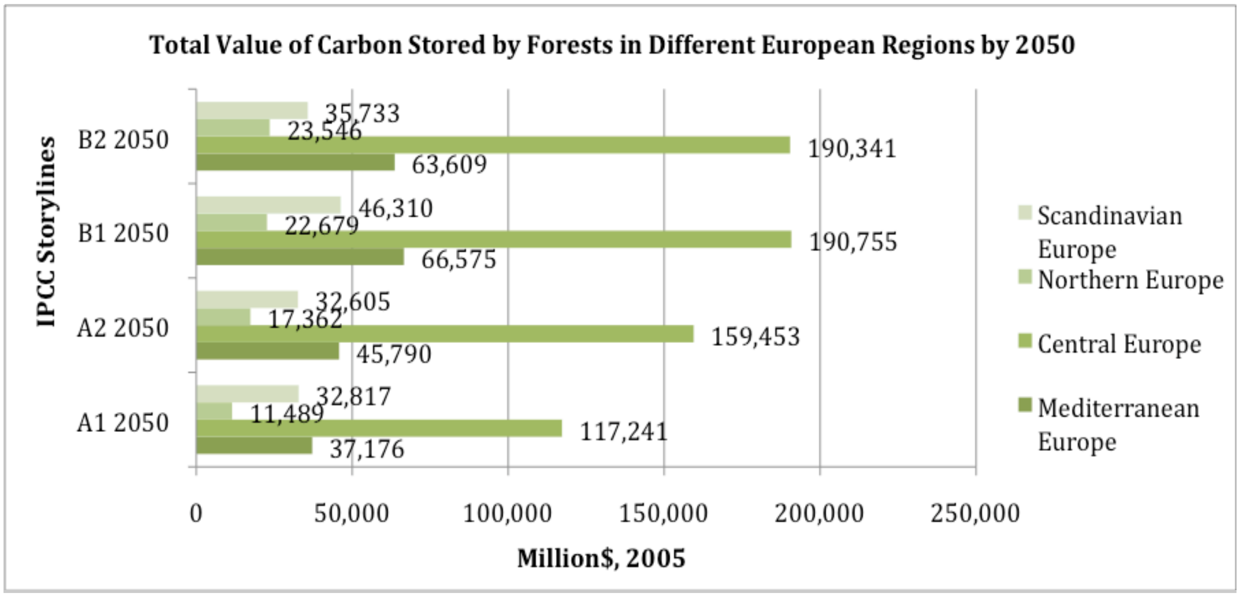

Figure 6. Forest carbon sequestration values

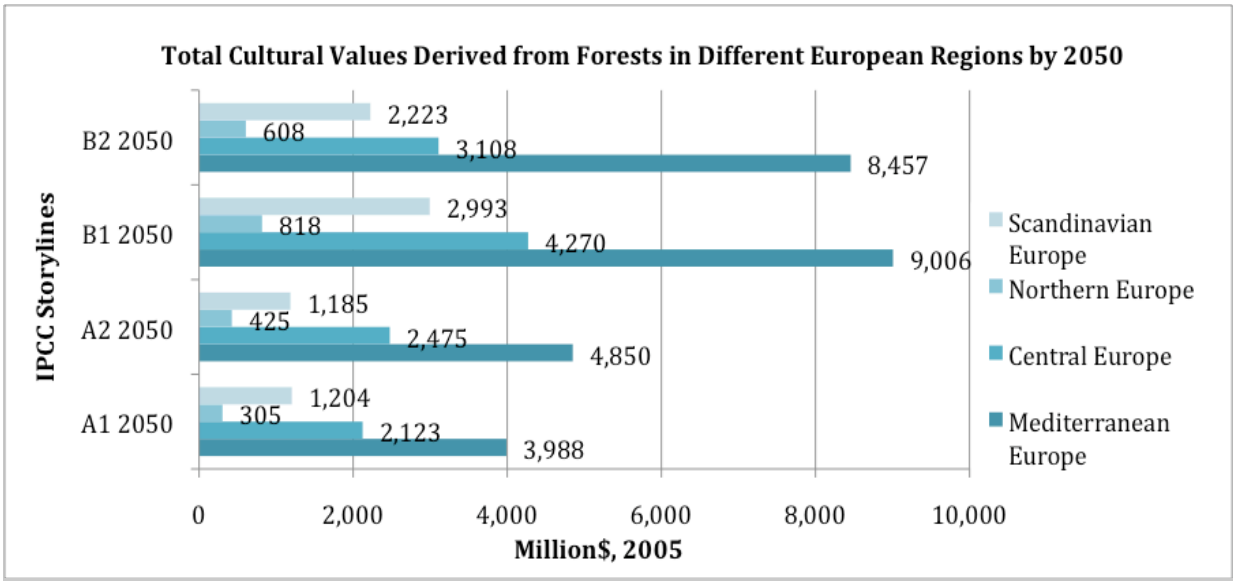

Figure 7. Forest cultural values

Furthermore, the impact of the climate change on biodiversity, and its welfare evaluation in terms of the respective changes on the provision of forest ecosystem goods and services, is multifaced. First, it depends on the nature of the forest good and service under consideration. For example, cultural values reveal to be more sensitive to the four IPCC scenarios than the values of other ecosystem services, with the wood forest products as the most *resilient* to climate change. Second, the distributional impacts of climate change on the provision of EGS also depend on the geo-climatic regions under consideration. In other words, these impacts are not distributed uniformly across the European countries under consideration. This becomes particularly clear by means of a comparative analysis – see Table 16.

Table 16. Comparison of Total Value of Forest Ecosystem Goods and Services in Europe across the four IPCC storylines

Geographical regions	EGS	Absolute value difference (Million$, 2005)			Change in %		
		A1vs.A2	B1vs.A2	B2vs.A2	A1vs.A2	B1vs.A2	B2vs.A2
Mediterranean Europe (N35-45)	WFPs Provision	-40	1,565	2,283	-1%	24%	35%
	Carbon Stock	-8,614	20,785	17,819	-19%	45%	39%
	Culture Service	-862	4,156	3,607	-18%	86%	74%
Central Europe (N45-55)	WFPs Provision	-6,306	-6,115	1,186	-13%	-13%	2%
	Carbon Stock	-42,212	31,303	30,888	-26%	20%	19%
	Culture Service	-352	1,795	633	-14%	73%	26%
Northern Europe (N55-65)	WFPs Provision	-1,802	-2,503	-405	-25%	-35%	-6%
	Carbon Stock	-5,874	5,317	6,183	-34%	31%	36%
	Culture Service	-121	393	182	-28%	92%	43%
Scandinavian Europe (N65-71)	WFPs Provision	1,597	-2,171	-1,999	5%	-6%	-6%
	Carbon Stock	212	13,705	3,128	1%	42%	10%
	Culture Service	18	1,808	1,038	2%	153%	88%

Table 16 depicts the welfare changes of different future states of the world associated to a potential deviation from the A2 scenario, a selected benchmark scenario. Our computation shows clearly see that the countries within the Mediterranean Europe geo-climatic zone (Greece, Italy, Portugal, Spain, Albania, Bosnia and Herzegovina, Bulgaria, Serbia and Montenegro, Turkey and Yugoslav) will benefit from the highest welfare gain in moving towards a B1 or B2 storyline. In fact, this geo-climatic zone can assist to a welfare gain amounting to an 86% increase in the cultural values when moving from an A2 towards a B2 scenario. This is followed by an increase of 45% in the value of the carbon sequestration services and a 24% increase in the value of the wood provision services. In other words, not adopting a B2 storyline, but instead moving towards an A2 scenario, will be associated to a high welfare loss in Mediterranean Europe owing to the reduced quantity and quality of the forest ecosystem services under consideration. Alternatively, moving from an A2 scenario towards an A1 scenario will always involve a welfare loss for Mediterranean Europe. In short, Mediterranean Europe scenarios will always be associated to a reduced quantity and quality of forest ecosystem services and thus, result in loss of human welfare. On the contrary, storyline B1 is ranked as the most preferred scenario for this geo-climatic area.

Scandinavian Europe (including Finland, Norway and Sweden), however, presents mixed results. First, moving from an A2 towards an A1 will not involve any welfare loss, on the contrary, small welfare gains can be registered even if not statistically significant from zero. Furthermore, the adoption of any B type scenario will always be associated to a welfare loss when considering the provision of wood products. Finally, Scandinavian Europe will also present significant welfare gains in the provision of the cultural and carbon sequestration services when moving towards any B type scenario. The respective welfare gains are, however, much lower when compared to the Mediterranean Europe, *ceteris paribus*.

Having the Mediterranean and the Scandinavian Europe as the two ‘corner situations’, we can observe that Central and Northern European regions present an intermediate state of affairs. In any case, it is important to remark that moving from an A2 towards an A1 scenario will be always associated to high welfare losses in all of the three services under consideration, having the highest losses registered among the Northern European countries (Denmark, United Kingdom, Estonia, Latvia and Lithuania). Unlike the Mediterranean and Scandinavian regions, the B type scenario for Central Europe present mixed results on climate change, where welfare loss is mainly caused by a change in the provision of WFPs. On the contrary, for Northern Europe these scenarios always provide lower values on WFPs, when compared to A2, which is a comparable situation to the Scandinavian region. Finally, both Central and Northern European regions show a similar profile for carbon sequestration and cultural values: any B type scenario is characterized by a welfare gain from the perspective of these two ecosystem services, a welfare impact, which is in accordance to that are registered in the Mediterranean and Scandinavian Europe.

Notwithstanding the uncertainties related to climate change, our assessment of the climate change impacts has shown some interesting results that are potentially useful for policy implications. There is obviously a need for optimal forest management strategies in Europe to cope with climatic shocks on the regional ecosystems and to promote the sustainable use of forest resources for satisfying long-term human demand. However, the design and implementation of these policies should respect the specific local environmental, economic and political context of each country. In other words, there are no *silver bullet* policies that can be applied to the European context as a whole. This refers to a bottom-up management approach to effectively manage forest resources at country level. On the other hand, by comparing the welfare gains/losses of climate change impact occurred in different geo-climatic regions, the EU will be able to evaluate the cost-efficient policy alternatives across all of the member countries. Therefore, the countries that suffer the most losses from climate change may be compensated through other supplementary policy package imposed by the EU. This infers a top-down approach to improve the overall efficiency of resource management in Europe.

In conclusion and to the best of our knowledge, the current paper represents the first systematic attempt to estimate human well-being losses with respect to changes in biodiversity and forest ecosystem services which are directly driven by climate change. However, we acknowledge the complexity in mapping, modeling and estimating the relationships between climate change, biodiversity, ecosystem functioning, ecosystems services and human welfare. Against this background, we subscribe to the ongoing 'Potsdam Initiative'[23] for biodiversity, also suggesting that it is imperative to continue further with a global study so as to have a better understanding of the linkages between biodiversity and human well being, especially in the context of global change.

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[23] At the meeting of the environment ministers of the G8 countries and the five major newly industrializing countries that took place in Potsdam in March 2007, the German government proposed a study on 'The economic significance of the global loss of biological diversity' as part of the so-called 'Potsdam Initiative' for biodiversity. The following was agreed at Potsdam: 'In a global study we will initiate the process of analysing the global economic benefit of biological diversity, the costs of the loss of biodiversity and the failure to take protective measures versus the costs of effective conservation.'

CHAPTER 3 WHEN MICRO- AND MACRO-ECONOMICS MEET TOGETHER TO REVEAL THE TRUE VALUE OF CLIMATE CHANGE IMPACT, CONFLICTS OR COMPLEMENT?

Ding, H., Nunes, P.A.L.D., Bosello, F., and R. Parrado (under preparation) 'When Micro- and Macro-Economics Meet together to Reveal the True Value of Climate Change Impact, Conflicts or Complement?', under preparation for submission to *Journal of Environmental Economics and Management*

Abstract

This paper explores the potential to incorporate micro- and macro- economic analysis in the estimation of the socio-economic impacts of climate change-induced changes in biodiversity and ecosystems. Biodiversity and ecosystem services are interpreted as important components of the world economic system. In this study, we tries to incorporate ecosystem services into a macro economic mechanism, where the world economy is assessed by a set of computable general equilibrium (CGE) models. Within this framework, changes in carbon sequestration provided by European forests are incorporated into a CGE model through a global warming approach, which allows the consideration of climate change impacts on forest carbon sequestration services and to re-compute a temperature equivalent induced by the higher release of CO2 emissions in the atmosphere resulting from climate change. On the basis of this new information, we then re-estimate all of the climate change impacts considered using the CGE model and recalculate new macro-regional GDP effects. The differences between climate change impacts on GDP considering the original and the new carbon sequestration levels are used as an approximation of the general equilibrium value of the changes in the European forest carbon sequestration service. This innovative approach allows us to explore the scaling-up potential of regional climate change impacts on biodiversity and ecosystem services and to identify the winners and losers of climate change impacts at a larger geographic scale.

Keywords: biodiversity and ecosystem services, climate change, Partial-General Equilibrium model

JEL: Q51, Q54, Q57

Note: An earlier version of this manuscript has been presented in the 2010 WCERE conference, held in Montreal, Canada and has been included in the Conference Proceedings.

3.1 Introduction

The impacts of climate change on biodiversity and the importance of biodiversity and ecosystem services to climate change adaption measures have long been a policy concern of the United Nations Framework Convention on Climate Change and United Nations Convention on Biological Diversity (UNCBD).

In 2002, following a UNCBD formal request, the Intergovernmental Panel on Climate Change (IPCC) prepared a technical report on Climate Change and Biodiversity. According to this report climate change is recognized as impacting ecosystems and biodiversity and at the same time "it is also possible that the current effort to conserve biodiversity and sustainably use ecosystem can affect the rate and magnitude of projected climate change" (IPCC, 2002: 41). Change in genetic or species biodiversity can alter the structure and functioning of ecosystems and therefore affect the water, carbon, nitrogen, and other major biogeochemical cycles. These in turn will influence the stabilization of ecosystem functioning and the overall provision of ecosystem goods and services. Finally, since ecosystem goods and services are important constituents of human-wellbeing, the consequences of climate-change-induced change in biodiversity and the underpinning ecosystems, in the structure and functioning of ecosystems and in the provision of ecosystem goods and services are ultimately detected in terms of welfare losses – see Figure 1.

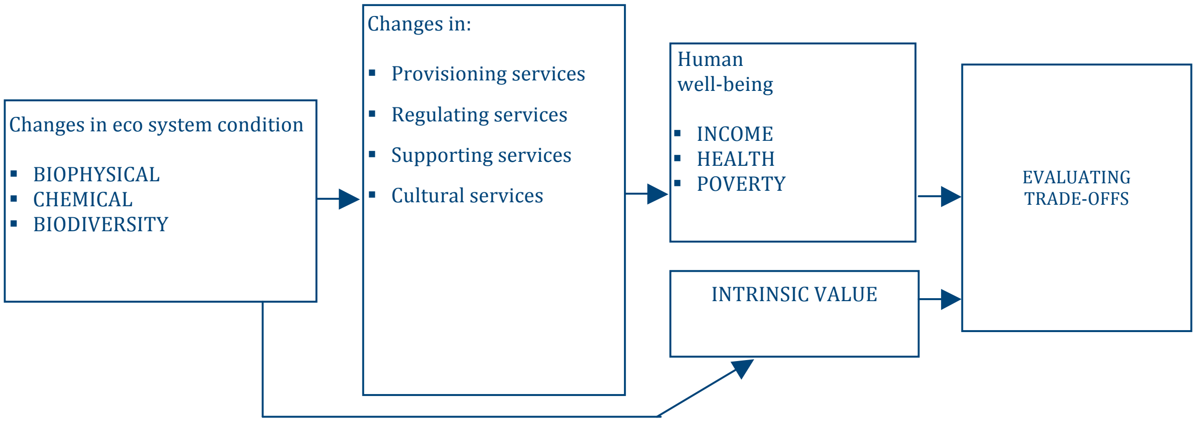

Figure 1. Biodiversity, ecosystem services and human wellbeing (Source: adapted from MA, 2005)

Alternatively, biodiversity conservation and sustainable use of ecosystem goods and services can affect the rate and magnitude of projected climate change and can thus play a potential role in adaption policies, including land-use based options. Therefore the economic value estimation results of climate-change-caused impacts on biodiversity and ecosystem services are important to shed light on the significance of this policy mechanism within any post-Kyoto climate negotiations.

In this context, we propose to contribute to the ongoing study of the relationship between biodiversity, ecosystem services and human well-being. In addition, this investigation is performed within a context of global change, and in particular global climate change, exploring the associated implications of the results of this study for policy design. In particular, this paper will address a number of policy challenges, such as what are the welfare losses induced by climate change impacts on European biodiversity and ecosystem services? How does the re-distributional map of the losses looks like? Do countries face similar welfare impacts of climate change? Are the welfare impacts similar across different types of ecosystems? Are the welfare impacts similar across different ecosystem services? Finally, what are the welfare benefits of integrating biodiversity and ecosystem services benefits into a more comprehensive future climate policy regime? To answer these questions, we will explore innovative approaches that go beyond the conventional economic modeling approaches and try to incorporate the dynamics of climate change induced ecosystem changes into the analysis of global economic system. The resulting value estimates may contribute to policymaking that improves the cost-effectiveness of emission control, taking into account natural process of ecosystems that regulates climate system and sequestrate CO2 emissions.

The paper is organized as follows. Section 2 reviews the state-of-the-art economic valuation techniques and models for valuing ecosystem services and for estimating the costs of climate change. The pros and cons of two main streams of economic analysis, i.e. micro- and macro-economic approaches will also be discussed. Section 3 develops an innovative approach that is labeled as partial-general equilibrium to re-estimate the costs of climate change impact on regional ecosystems. This new approach will be applied to the European forest ecosystem under climate change scenario. Results are also presented and discussed. Section 4 discusses the lessons learned from both micro-and macro- economic valuation approaches to estimate the value of ecosystem services as well as their policy implications. Section 5 concludes the main results of the research.

3.2 A Review of Economic Valuation Approaches to Value Climate Change Impacts on Nature

Economic valuation is rooted in the micro-economic theory, where values are measured based on individual preferences and choices. People express their preferences through the choices and tradeoffs that they make, given certain constraints, such as those on income or available time. Value is therefore revealed in decisions about how individuals or society collectively choose to allocate their resources. Therefore, economic valuation of ecosystem services has important policy implications when limited resources are available to be allocated among a set of conservation or resource management plans. Decisions need to be made based on the tradeoffs of various benefits, including both marketed and non-marketed ones, provided by ecosystem under different resource use options or management strategies.

Economists measure the value of ecosystem services to people by estimating the amount people who are willing to pay to preserve or enhance the services. However, this is not always straightforward. In particular for many ecosystem services that are not traded in the market, people do not purchase them directly, and thus face difficulties to express their willingness to pay for those services under conservation. For this reason, various economic valuation techniques are needed to capture both market and non-market value aspects of ecosystem services. In Table 1 below, we summarize the standard ecosystem valuation techniques that are mostly used in the literature.

In the case of climate change, it has already affected many ecosystems as well as their functioning and capacity to provide goods and services to humans. Thus the socio-economic valuation of those impacts is anchored in the assessment of changes in the productivity of the economic sectors under concern and/or in the measurement of maximum amount individuals who are willing to pay for avoiding the reduction of ecosystem services caused by continuous increase in temperature and precipitation rates – see Figure 1. The estimated economic benefits of biodiversity and ecosystems should reflect the welfare changes of the individuals being directly affected by changes in biodiversity and ecosystems, or the average welfare change of the individuals in a considered population (Nunes et al. 2003).

Table 1: Tool box of economic valuation techniques

Category	Technique	Description	Example
Revealed preference approaches			
Market prices	Market prices	How much it costs to buy an ecosystem good or service.	The price of timber or mineral.
Production function approach	Effect on production	Relates changes in the output of a marketed good or service due to the changes in a measurable amount of production inputs.	The reduction in lifespan of a hydro.
Surrogate market approach	Travel costs	Valuation method based on the willingness to pay for recreational/ leisure use of nature resources, derived from the amount of time and money people spend on visiting a relevant ecosystem.	The transport and accommodation costs, entry fees and time spent to visit a natural park.
	Hedonic pricing	The difference in property prices or wage rates that can be ascribed to the different ecosystem quality or values.	The difference in house prices between those overlooking an area of natural beauty and those without a view of the landscape.
Cost-based approach			
Damage costs avoided		The costs incurred to property, infrastructure, production when ecosystem services which protect economically valuable assets are lost, in terms of expenditure saved.	The damage to roads, bridges, farms and property resulting from increased flooding after the loss of catchment protection forest.
Stated preference approaches			
Contingent valuation method		Infer ecosystem value by asking people directly what is their willingness to pay (WTP) for resource conservation or willingness to accept for (WTA) compensation for the loss of biodiversity/ ecosystems	How much would you be willing to contribute towards a fund to clean up and conserve a river?
Conjoint analysis		Elicit information on preferences between scenarios involving ecosystems between which the respondents would have to make a choice, at different price or cost saved.	The relative value wildlife, landscape and water quality attributes of a river under different conservation scenarios, relative to the status quo.
Choice experiments		Presents a series of alternative resource or ecosystem use options, each defined by various attributes including price and asks respondents to evaluate these “sets”, which each contain different bundles of ecosystem services.	Respondents’ preferences for conservation, recreational facilities, and educational attributes of natural woodlands.
Value transfer approaches			
Meta-analysis		This technique takes the result from a number of studies and analyses in such a way that the variation in value of ecosystem services obtained in those primary studies can be explained.	Analysis of many primary contingent valuation studies for woodlands to derive the trends in the key variables affecting visitor WTP values for woodlands, to establish a suitable variable for adjustments for the site to be assessed.

Source: adapted from WBCSD (2009)

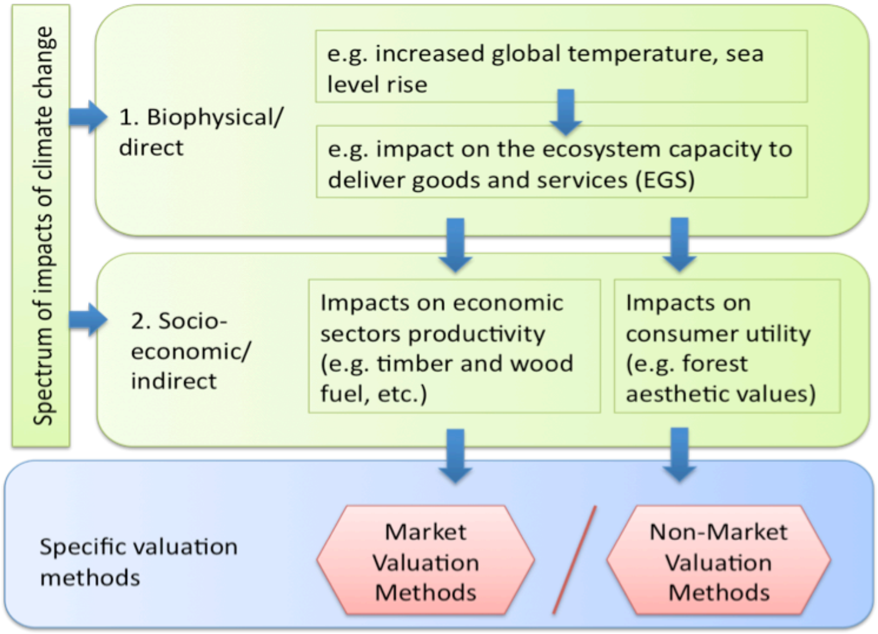

Figure 2. A valuation framework for assessing climate change impacts from a mirco economic perspective (Source: adapted from Australian Greenhouse Office report, 2004)

Take forest ecosystem as an example, it provides both marketed ecosystem services (e.g. timber) and non-marketed ecosystem services (e.g. watershed protection and climate regulation). Therefore, the monetarisation of climate change induced loss of forest ecosystem services requires the exploration of economic theories and different valuation methodologies. On the one hand, for the ecosystem services traded in the market, direct market price method can be used to estimate an individual’s willingness to pay for them. On the other hand, the non-market benefits provided by ecosystems cannot be directly measured using market information, but they are probably the most important benefits to the support of local livelihoods. To capture these value aspects, economists use revealed or stated preference valuation methods, such as cost assessments methods, travel costs methods and contingent valuation methods. Recently, there is also an increasing use of meta-analysis and value transfer methods to study the costs and benefits of ecosystem services at a larger geographic scale. However, it is important to note that these techniques are most appropriately applied in the context of regional or national scale of climate change impacts, disaggregated by sector or market. The use of economic valuation techniques in isolation (sometimes referred to as ‘bottom-up’ studies) is predicated on an assumption that any incremental damage due to climate change will not have large, indirect (non-marginal) impacts, affecting the prices of a range of goods and services that flow through the macro-economy.

Nevertheless, the impacts of climate change is rather a global phenomena that affects all types of ecosystems and the values and services they provide to people, and the spatial distribution of these effects has shown a heterogeneous pattern across the globe. Models suggest that global net primary production (NPP) has already increased in response to changes in temperature and precipitation during the 20th century (Del Grosso *et al* 2008). Regional modeling also projects increases in NPP for some regions (Olesen et al. 2007), for example 35-45 per cent for northern European ecosystems, as a result of longer growing seasons and higher CO2 concentrations. However, where water balance is more important, as in southern Europe, NPP is projected to decline or to increase only slightly relative to present day conditions. This thus involves winners and losers at different geographical scales. In this context, a comprehensive valuation of costs and benefits of climate change will be critical to the design of financial mechanism allowing the losers at different regional or national scales to be compensated.

A most recent study dealing with the monetization of distributional climate change impacts is provided by Ding et al. (2010), who have proposed a three-step approach to value the changes in ecosystem goods and services provided by European forest ecosystems in the context of climate change. The first step is the determination of the role of biodiversity in creating relevant ecosystem services. The second step is the calculation of the reduced quantity and quality of these ecosystem services resulting in loss of human welfare under alternative climate scenarios, which contains the four A1, A2, B1 and B2 scenarios proposed by the IPCC. The third step is the (monetary) valuation of that loss – see Figure 2. The methodology is anchored in a micro-economic valuation approach.

Their results have shown that among all values provided by forest ecosystem services, cultural values reveal a greater sensitivity to climate change. On the contrary, provisioning services are observed to be more resilient to climate change. Estimation results show that climate-change-caused impacts on biodiversity and ecosystem services present significant spatial distributional patterns. Taking the B2 scenario as an example, and 2050 as the year of analysis, Central European countries are ranked the highest in the provision of forest provisioning services (about 48.7 billion$, measured in 2005 USD and corrected for PPP) and carbon sequestration services (about 190.3 billion$) but are ranked second in terms of cultural services provision (about 3.1 billion$). Conversely, Mediterranean Europe demonstrates exactly the opposite welfare pattern, registering the highest cultural value, about 8.4 billion$. The Scandinavian geo-climatic area is the second largest contributor to forest provisioning services in Europe (accounting for 31.9 billion$). Here carbon sequestration services amount to 35.7 billion$ and cultural services 2.2 billion$. In contrast, A1 scenario Mediterranean Europe registers the lowest values regarding cultural services (about 3.9 billion). When compared to B2, Central Europe registers a slight reduction in the forest provisioning services, now with values around 41.2 billion$. On the contrary, Scandinavia in the A1 scenario registers a small increase, with current values around 35.5 billion$. Finally, Central Europe has a high reduction in carbon sequestration values, now amounting to 117.2 billion$. A reduction of smaller magnitude is also registered in the carbon sequestration values mapped in the Scandinavian countries, now amounting to 32.8 billion$.

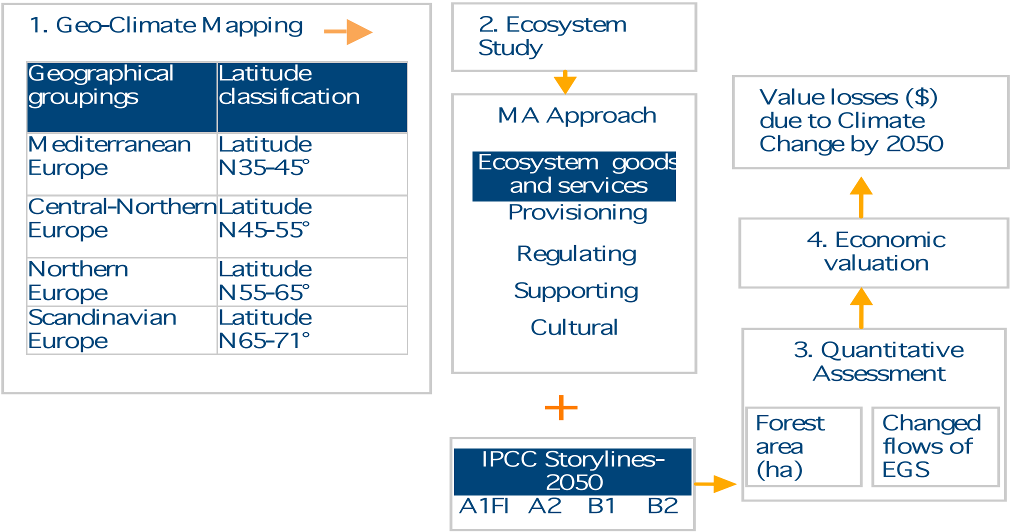

Figure 3. Valuation of ecosystem goods and services in the context of climate change
(Source: adapted from Ding *et al*, 2010)

However, the limitation of this study is that it spots only a small portion of the global economy at a small scale (i.e. Europe) that may suffer or benefit from the continuous climate change. Today, our global economic system is so well connected that it cannot be immunized from any tiny disturbance in the regional or local economies. Therefore, one may want to explore the use of alternative economic tools to understand the larger scale economic consequence of regional climate change impacts on ecosystems. This invokes us to explore the potential of a macroeconomic perspective that is carried out using computable general equilibrium (CGE) models to assess climate change impacts on the global economic system, via market dynamics at national and regional scales.

Current literature provides a significant quantity of research on the application of economic modelling to the estimation of socio-economic costs of climate change damage, also known as

Integrated Assessment Models – IAMs, developed primarily for the purpose of assessing policy options for climate change control, by definition combining the socio-economic aspects of global economic growth with the scientific aspects of geophysical climate dynamics. Well-known IAMs in the literature include MERGE, IMAGE, FUND, and DICE, with a focus on global estimates of carbon stocks. These models are characterised by significant differences that can all affect these final estimates including levels of modelling detail, in their respective capacities to deal with climate-economic-atmospheric complexity and the economic modelling strategy, in their capacities to deal with uncertainty and in their abilities to incorporate economic responses.

Despite significant scientific investigation, the economics of climate change is still not well understood due to the high uncertainties of climate change impacts in the long run (Kelly and Kolstad, 1999). More ambitious and controversial approaches of cost-benefit analysis require additional information about the monetized value of climate impacts, which is necessary to calculate the "optimal" policy, or to determine whether a particular policy is "worthwhile" (Ackerman and Finlayson, 2005). In addition, most of these impact studies take a static approach (Tol, 2002a; Watson et al., 1996; Pearce et al., 1996; Tol et al., 2000), whereas climate change is rather a long-term dynamic process, involving the complexity of interface between physical and economic dynamics, such as the increasing CO2 concentration, the growing world population and economy, and the evolving technologies and institutions (Tol, 2002b). More precisely, the consequences of climate instability and rapid large-scale shifts in global climate may interfere in the economic production function in many sectors (e.g. forestry, and tourism), whereas the socio-economic development is always the embedded driving force behind climate change. To date, economists have been putting more effects on moving the state of the art IAMs towards a dynamic approach (e.g. Tol, 2002b). In particular, to the best of our knowledge, none of the existing IAM model has ever incorporated the dynamics of ecosystem changes under climate change impacts into the projections of economic system. Thus, the rest of the paper will focus on exploring an alternative modelling approach, namely partial-general equilibrium model approach that brings together the two different economics domains by integrating ecosystem-based impact assessment into the study of climate system dynamics as well as the regular cost-benefit analysis of climate change impacts, with particular attention to the regulating services of ecosystems.

3.3 Developing a Partial-general Equilibrium Perspective Using ICES Model

The proposed partial-general equilibrium model encompasses two steps: First, the magnitude of climate change impacts on forest productivity and carbons sequestration is isolated and estimated in an integrate-hybrid valuation model. Second, the information provided by the integrate-hybrid valuation model is used to revise the original forest productivities in a CGE model, where land productivity enters as an exogenous variable and its level is decided by the user and calibrated in the model so as to mirror current conditions as closely as possible. At that stage we are then able to use the CGE model to re-compute the new equilibrium caused by biodiversity productivity shocks.

The methodology and results of step 1 are reported in Chapter 2. Therefore, in this chapter, we will focus on step2, demonstrating how to develop the partial-general equilibrium model. In this study, the economic implications of climate change are determined by using a multi-country world CGE model: ICES. Based on the Global Trade Analysis Project (GTAP) database version 6 and core model (Hertel, 1996), ICES develops a recursive-dynamic growth engine where a sequence of static equilibria are linked by the process of capital accumulation driven by endogenous investment decisions. The specification of the supply side of the model follows Burniaux and Truong (2002), with extended details in the description of energy production. The model runs for the period between 2001 and 2050 on a yearly basis.

It is an essential first step to build a benchmark for the study period, during which investment choices and resulting capital stocks are determined endogenously in the model, whereas other key economic variables in the calibration dataset of the model are exogenously updated, allowing us to identify a hypothetical general equilibrium state in the future (This methodology is described in Dixon and Rimmer, (2002)). In particular, changes in the national endowments of population/labour, land, natural resources, as well as variations in factor-specific and multi-factor productivity are projected by justifying these variables on the supply side. In this study, estimations of future changes of the production endowments were taken from various databases. For example, the future regional labour stocks were taken from UNDP (2008); whereas estimates of land endowments and agricultural land productivity were derived from the IMAGE model version 2.2 (IMAGE, 2001). As for the natural resources stock variables, a rather specific methodology was adopted. We choose to apply exogenous prices of the natural resources in the model so that computer will endogenously generate the optimal amount of natural stocks being used in the production over time. For instance, the prices of specific natural resources, such as oil, coal and gas have been set to mimic what was forecasted by EIA (2009). Finally, by changing the calibration values for these variables, the CGE model was able to simulate a general equilibrium state for the future world economy, referring to a benchmark where no economic impacts of climate change have taken place, whereas the counterfactual scenarios consider the effects generated by one or more impact factors. For the purpose of comparison between different possible future development paths, the social economic scenario A2 of the IPCC is chosen as a reference future state of climate change.

3.3.1 A new approach to evaluate the costs to the EU Economic System due to climate change impacts on forest ecosystem

To assess the general equilibrium implications of climate change impacts on ecosystems services, each of these services is first translated into a marketable item and then into changes in the appropriate economic variables that act as inputs into or constitute outputs from the CGE model. For instance, climate-change induced changes in forest ecosystem provisioning services are modelled as changes in the productivity of the natural resource inputs used by the European timber industries. Whereas the general equilibrium assessment of changes in European forests' carbon sequestration services follows a different path. Changes in forest based carbon sequestration alter the GHG's balance between land sinks and the atmosphere, thereby causing a temperature change that can be defined over a period of time. Taking this into consideration, we use a global warming approach, which to the best of our knowledge has never been performed under a CGE modelling framework. This exercise consists of the formulation of a scenario where the carbon sequestration services from European forests are affected by climate change, thereby producing a different CO2 concentration level in the atmosphere and a corresponding variation in temperature. That change in temperature in its turn impacts the economy at various levels that can then be assessed through the use of the ICES model. Accordingly, we first compute a *temperature equivalent* induced by the higher release of CO2 emissions in the atmosphere resulting from climate change. On the basis of this new information, we then re-estimate all of the climate change impacts considered using the ICE model and recalculate new macro-regional GDP effects. The differences between climate-change impacts on GDP considering the original and the new carbon sequestration levels are used as an approximation of the general equilibrium value of the changes in EU forest carbon sequestration service.

3.3.2 Results

Table 2 summarizes the changes of forestry productivity from the new CGE calibration under different scenarios of temperature increase, which was estimated using information about carbon stocks projected by the integrate-hybrid valuation model. Our results show that forest timber productivity declines in the Mediterranean Europe but increases in other European areas, in particular the Northern Europe. These changes are due to biodiversity/ecosystem effects and are used to adjust the information originally utilized in the ICES model.

Table 2: Climate change impacts on ecosystem services (% change wrt 2000, reference year 2050)

	Forest productivity (timber)	
	+1.2°C T wrt 2000	+3.1°C T wrt 2000
Med_Europe	-6.08	-15.70
North_Europe	15.09	38.97
East_Europe	4.48	11.56

Moreover, as far as forest carbon sequestration is concerned, a temperature smoothing potential of European forests by 2050 can be computed, if climate change induced impact on European forest carbon sequestration services is integrated into the ICES model. As a consequence, this consideration leads to an increase of 0.018°C in future temperature by 2050, resulting a considerable GDP impact across globe. Thus, we recalculated the GDP difference between the simulations with and without climate change impacts on ecosystem services to understand resulting economic loss of climate change. In Table 3, we reported the estimated changes of GDP for major world economic regions in a context of climate change. The GDP estimates that are calculated over the period 2001-2050 (at a 3% discount rate) corresponding to two different temperature increase scenarios, which assume future temperature increase will be *+ 1.2°C and + 3.1°C* by 2050, respectively. The estimated GDP difference implies a fact that regions damaged or advantaged by climate change may experience different welfare impacts by 2050.

Table 3. Climate change impact on GDP without (1) and with (2) impacts on ecosystem and biodiversity

Region	*+ 1.2°C T wrt 2000* Climate Change impacts on GDP NPV 2001-2050 (dr=3%) Million US$			Year. av. (2001-2050)	*+ 3.1°C T wrt 2000* Climate Change impacts on GDP NPV 2001-2050 (dr=3%) Million US$			Year. av. (2001-2050)
	Part I (1)	Part I and Part II (2)	Difference (2) – (1)		Part I (1)	Part I and Part II (2)	Difference (2) – (1)	
USA	-266,294	-270,566	-4,273	-87	-631,392	-635,746	-4,354	-89
Med_Europe	-33,979	-34,476	-497	-10	-65,084	-63,792	1,292	26
North_Europe	488,420	496,059	7,639	156	1,360,399	1,372,541	12,142	248
East_Europe	-20,808	-21,189	-381	-8	-101,529	-103,035	-1,506	-31
FSU	-21,482	-22,422	-941	-19	-214,426	-222,225	-7,799	-159
KOSAU	-71,135	-72,260	-1,125	-23	-172,240	-173,401	-1,160	-24
CAJANZ	102,803	104,473	1,670	34	361,249	366,294	5,044	103
NAF	-50,229	-51,229	-1,001	-20	-210,749	-215,451	-4,702	-96
MDE	-221,033	-224,571	-3,537	-72	-620,101	-626,561	-6,460	-132
SSA	-52,729	-53,895	-1,167	-24	-218,737	-222,748	-4,010	-82
SASIA	-368,147	-375,246	-7,099	-145	-1,474,608	-1,503,348	-28,740	-587
CHINA	-431,586	-438,733	-7,147	-146	-1,863,000	-1,887,020	-24,020	-490
EASIA	-212,334	-215,812	-3,478	-71	-730,920	-739,675	-8,755	-179
LACA	-332,006	-337,790	-5,784	-118	-995,229	-1,007,254	-12,025	-245
Europe	433,633	440,394	6,761	138	1,193,786	1,205,714	11,928	243
World	-1,490,538	-1,517,658	-27,120	-553	-5,576,367	-5,661,421	-85,054	-1,736

NB: % change wrt no climate change baseline (ref. year 2050, 3% discount rate)

For example, Table 3 shows a loss (that is, a lower gain) for Mediterranean Europe ranging from 9.7 to 32.5 billion US$, a higher loss for Eastern Europe ranging from 7.2 to 22 US$ billion, and a slight gain for Northern Europe ranging from 2 to 5.6 US$ billion. In addition, the table also shows a magnified global climate change impact if total carbon sequestered by the European forests are reduced due to climate change. For instance, at a global level, and depending upon the climate change scenario, the damage imposed by climate change on carbon sequestration services provided by European forest ecosystems can cost on average 553 to 1736 million US$ per year. These figures monetize the negative GDP performances of all the economies considered due to lower carbon sequestered by European forests as a result of higher temperature increases. Alternatively, if we only focus on Europe, we can find that a reduced carbon sequestration service provided by European forest ecosystems implies a welfare *gain* that ranges from 138 to 243 million US$ on a yearly base. Although for Mediterranean and Eastern Europe the net welfare effect of the carbon sequestration services provided by ecosystems is positive as higher temperature are "bad" for them, it is negative for Northern Europe which ultimately gains from climate change. To better understand the climate change induced ecosystem impacts on future GDP in Europe, we extracted the GDP estimates and re-organize them in Table4 below.

Table 4. Contribution of carbon sequestration services from European ecosystems to global climate change regulation (in billion US$, at 3% discount rate)

Region Model	CGE (1)	CGE & BES (2)	(2) – (1)	Year average (2001-2050)
Med Europe	-34	-34	-0.5	-0.01
	-65	-64	+1.3	+0.03
North Europe	+488	+496	+7.6	+0.16
	+1,360	+1,373	+12.1	+0.25
East Europe	-21	-21	-0.4	-0.01
	-102	-103	-1.5	-0.03
World	-1,491	-1,518	-27.1	-0.55
	-5,576	-5,661	-85.1	-1.74

In Table 4, the first column shows the valuation results from the CGE model. The second column shows the estimation results of the CGE with the biodiversity and ecosystem services, BES – see CGE & BES model. The third column depicts the differences. All magnitudes are measured in terms of projected changes in GDP with respect to no climate change baseline for the reference year 2050. There are two value estimates per region, for a mean temperature increase of 1.2 and 3.1 degrees Celsius, respectively. In general, our results show that over the fifty-year period the NPV for the Mediterranean Europe now ranges from, -34 to -65 billion US$, depending on the two temperature scenarios under consideration. Therefore, when compared to the original welfare computations, this implies a higher loss for Mediterranean Europe ranging up to 0.5 billion US$. In other words, climate-change-caused impacts on biodiversity and ecosystem services cause an additional welfare loss to Mediterranean Europe. A similar welfare pattern is registered in the East Europe. Note, however, that the North Europe region has a welfare gain due to climate change, whose magnitude is reinforced when BES is embedded. In fact, this is responsible for an additional welfare gain that ranges between +7.6 and +12.1 billion US$, depending on the temperature scenario. Finally, at a global level, and depending upon the climate change scenario, our model result suggests that the damage imposed by climate change on carbon sequestration services provided by European forests ranges from 27.1 to 85.1 billion US$. This loss is equivalent to an annual rent that ranges between 0.56 and 1.74 billion US$ over a period of fifty years.

3.4 Lessons Learned from Micro-and Macro- Economic Valuation Approaches to Estimate the Value of Ecosystem Services and the Respective Policy Implications

The economic valuation of the impacts caused by climate change on biodiversity and ecosystem services are multifaceted. Previous findings obtained using an integrate-hybrid economic valuation approach (by Ding *et al.,* 2010 – Chapter 2) reveal significant welfare impacts, however the respective dimension and distribution effects vary significantly across geo-climatic regions in Europe, and the magnitudes of the impact depends on the underlying IPCC storyline and the type of ecosystem services under consideration. In most of the cases, changes involved signal the presence of winners and losers, or different magnitudes of welfare loss. This aspect, i.e. the unbalanced distribution of climate-change-caused impacts on biodiversity and ecosystem services across Europe, signals the relevance of the issues of redistribution when approaching an efficient, broadly accepted international negotiation on carbon reduction. In conclusion, the advantage of a micro-economic assessment of the climate change impacts on ecosystem services can contribute directly to estimating economic loss from the reduced ecosystem services and productivity and to identifying the winners and losers at regional level. This information is of particular importance in the design of cost-effective and efficient environmental policies that reallocate resources among regions and stakeholders to achieve the United Nations' millennium development goals (MDGs) as well as the international target of GHGs reduction. At the same time, we should also recognize the limitation of such direct impact assessment for achieving the long-term sustainable development goals, as climate change is not only affecting ecosystem functioning and productivity locally, but the regional ecosystem disturbance may have far-reaching socio-economic consequences in the far distant future, through international trade and interactions between all the economies in the globe.

The partial-equilibrium model approach on the other hand can be complementary to the hybrid model approach, by incorporating regional climate change induced ecosystem impacts into the picture of world economy. As demonstrated in this paper, we can recalculate the changes of global economy under future climate change scenario by incorporating forest carbon sequestration service into the ICES model. Despite the fact that our model development is still at an early stage, i.e. taking into account only one type of ecosystem (forest) and one ecosystem service (carbon regulating services), our new findings are promising. First of all, our model results suggest that European forests have a potential to smooth temperatures as low as 0.018°C in 2050. Furthermore, we use this information to recalibrate the ICES model so as to re-compute the new equilibrium caused by biodiversity and carbon sequestration services.

Similar to the results of the hybrid evaluation model, the GDP value estimates from the partial-general equilibrium model show that there is no single welfare change pattern. In particular, for Mediterranean Europe the introduction of the Biodiversity and Ecosystems sector, modeled here in terms of the European forest sequestration services, does not imply significant additional welfare changes, when compared to the original CGE estimates. In fact, the magnitude of the welfare losses caused by climate change is approximately the same across the two model specifications under consideration. On the contrary, at a global level the damage imposed by climate change on biodiversity and carbon sequestration services provided by European forests ranges up to 85.1 billion US$. In other words, the key message delivered by this analysis is that the economic assessment of climate-change-cause impacts on biodiversity and ecosystem services highlights a substantive welfare loss. It is also true, that this is signal the tip of the iceberg: the analysis is here focused at biodiversity anchored at a single ecosystem type, forest, and a single ecosystem service produced by forests, carbon sequestration.

Taking into account (1) the forty four European countries and (2) the sequestration services from forests alone, climate-change-cause impacts on biodiversity and ecosystem services are responsible for welfare loss amounting to 85 billion USD$. If we also add (3) the biodiversity productivity effects on the agricultural sectors, (4) freshwater and coastal ecosystems this figures rises up to 145 - 170 billion USD$ (this is demonstrated in Bosello et al. 2009). If we consider the World Bank's global ranking with respect to GDP per capita, this amount corresponds to the aggregated GDP of the 22 poorest countries, which constitute 13% of the totality of world countries. These results lead to the main conclusion that autonomous adaptation cannot be invoked as the solution to climate change, but needs to be addressed with proper mitigation and planned adaptation strategies.

Furthermore, autonomous adaptation cannot reverse the adverse distributive implications of climate change. In other words, the present estimation results confirm that (1) climate change brings along significant welfare impacts, (2) biodiversity and ecosystem services play an important role in the determination of the final welfare magnitudes, and (3) not all European countries will have identical impacts, some countries will lose more than others, and some countries will gain, depending on their geographical location, the existing markets and profile with respect to biodiversity indicators and land use patterns. For these same reasons, it is important to use these results in the design of any climate-mitigation, or adaptation, policies.

Note, however, that one also needs to remember that the success of these negotiations will depend inter alia on key issues such as:

a. Uncertainty. Despite the evidence of climate change impacts, high uncertainty is associated with both distributional effects and the magnitude of these impacts. Therefore, a range of value estimates is preferred to a point estimate of the possible damage costs of climate change. The observed uneven distribution of climate change impacts represented a first impediment when scaling up the regional impacts across different geographic regions.

b. Intra-generation equity and vulnerability. Climate change is a global phenomenon, the impacts however tend to be more regional or site-specific in the area where the population is most vulnerable to climate change and usually exposed to extreme poverty. However, the existing micro-economic valuation approaches are mostly designed in favor of the relatively rich regions where willingness-to-pay for autonomous adaption measures such as ecosystem and biodiversity protection for climate is affordable. Therefore, the main difficulties of environmental economics were the scaling up of the damage costs across different populations and the efficient distribution of the benefits of global collective climate policies.

c. Inter-generation equity. The equal rights of future generations to enjoy a stable climate are subject to the choice of discount rate in the literature of environmental economics. It has been widely accepted that the current severe climate change is mainly caused by anthropogenic activities over the past century, but the question of how much of our limited resources we should invest to preserve the environment and stabilize the climate for future generations to come is still open.

All these aspects constitute important areas of debate among leading economists (Stern, 2006; Nordhaus, 2007, Weizman, 2007, and Tol, 2006) but in any case do not deny the significant, and additional, welfare impacts derived from bringing ecosystem services into the assessment of overall climate change impacts.

3.5 Conclusions

This paper explored the potential to incorporate micro- and macro- economic analysis in the estimation of the socio-economic impacts of climate change-induced changes in biodiversity and ecosystems. Biodiversity and ecosystem services were interpreted as important components of the world economic system. In this study, we tried to incorporate ecosystem services into a macro economic mechanism, where the world economy was assessed by a set of computable general equilibrium (CGE) models. Within this framework, changes in carbon sequestration provided by European forests were incorporated into a CGE model through a global warming approach, which allowed the consideration of climate change impacts on forest carbon sequestration services and to re-compute a temperature equivalent induced by the higher release of CO2 emissions in the atmosphere resulting from climate change. On the basis of this new information, we then re-estimated all of the climate change impacts considered using the CGE model and recalculated new macro-regional GDP effects. The differences between climate change impacts on GDP considering the original and the new carbon sequestration levels were used as an approximation of the general equilibrium value of the changes in the European forest carbon sequestration service. This innovative approach allowed us to explore the scaling-up potential of regional climate change impacts on biodiversity and ecosystem services and to identify the winners and losers of climate change impacts at a larger geographic scale.

In summary, the present estimation GDP value estimates confirm that (1) climate change brought along significant welfare impacts, (2) biodiversity and ecosystem services played an important role in the determination of the final welfare magnitudes, and (3) not all European countries would have identical impacts, some countries might lose more than others, and some countries might gain, depending on their geographical location, the existing markets and profile with respect to biodiversity indicators and land use patterns. Therefore understanding the magnitudes of welfare impacts is important for results in the design of any climate-mitigation, or adaptation, policies.

However, it is important to note that our study only signals the tip of the iceberg, for the present analysis only focused on biodiversity anchored in a single ecosystem type, i.e. forest ecosystem, and considered only a single ecosystem service produced by forests, carbon sequestration. If taking into account (1) the 34 European countries and (2) the sequestration services from forests alone, climate-change-cause impacts on biodiversity and ecosystem services are responsible for welfare loss amounting to 85 billion USD$. If we consider the World Bank's global ranking with respect to GDP per capita, this amount corresponds to the aggregated GDP of the 22 poorest countries, which constitute 13% of the totality of world countries. Nonetheless, if we also add (3) the biodiversity productivity effects on the agricultural sectors, (4) freshwater and coastal ecosystems, the total loss in GDP terms will be much higher. These results lead to the main conclusion that autonomous adaptation cannot be invoked as the solution to climate change, but needs to be addressed with proper mitigation and planned adaptation strategies.

Moreover, we should also recognize the dynamic aspect of ecosystem changes in response to direct and indirect socio-economic drivers, Today, Europe, along with many other countries, experiences the growing pressures from population growth, changing diets, urbanization, and climate change, which are causing continuous ecosystem degradation and biodiversity decline. In return, the changes in biodiversity and ecosystem cannot directly affect only our economic system, but also the capacity of natural ecosystems to mitigate and adapt to further climate change. These are externalities have already been impacting the conventional economic systems. Therefore, fully assessing the costs of these externalities, in particular the costs of losing biodiversity are important for the design of effective policy instruments to correct the failed market signals and to fully incorporate the costs of climate change into the economic mechanism. This way will enable us to prevent from further resource degradation and fight against climate change.

Finally, one should also note that the reorganization of the value of ecosystems and biodiversity is no longer "exclusive" to the academic and research arena, but has already been highlighted in current policy agendas. For example, at the recent meeting of environment ministers of the G8 countries and the five major newly industrializing countries in Potsdam in March 2007, the German government proposed a study on "The economic significance of the global loss of biodiversity" as part of the so-called "Potsdam Initiative" for biodiversity, with an aim of "initiating the process of analyzing the global economic benefit of biological diversity, the costs of the loss of biodiversity and the failure to take protective measures versus the costs of effective conservation". This proposal was endorsed by G8+5 leaders at the Heiligendamm Summit on 6-8 June 2007 and has led to one of the most important international research collaboration on "The Economics of Ecosystems & Biodiversity (TEEB)". On the other hand, as climate change will continue, they will have significant impacts on many aspects of biological diversity: including ecosystems, species, genetic diversity within species, and the ecological interactions, which in turn will significantly influence the long-term stability of the natural world as well as many benefits and services that humans depend upon (IPCC, 2007). The considerable socio-economic and ecological impacts related to climate change induced ecosystem impact have led to an increasing number of recent research attempting to advance our understanding of intercourse between climate change and biodiversity. However, future efforts are need to translate ecological impacts into economic values, which are the basis for any today's decision making.

CHAPTER 4 MODELING THE LINKS BETWEEN BIODIVERSITY, ECOSYSTEM SERVICES AND HUMAN WELL-BEING IN THE CONTEXT OF CLIMATE CHANGE: RESULTS OF AN ECONOMETRIC EXERCISE TO THE EUROPEAN FORESTS

Ding, H. and P.A.L.D. Nunes (under preparation) "Modeling the Links between Biodiversity, Ecosystem Services and Human Well-being in the Context of Climate Change: Results of an Econometric Exercise to the European Forests", under preparation for submission to *Journal of Ecological Economics.*

Abstract

The paper conducts an empirical investigation on the complex relationship between biodiversity and the values of ecosystem goods and services that are supported by biodiversity and ecosystem functioning, aiming to produce an econometric quantification of the magnitudes involved. Furthermore, we operate this study at a in the context of global climate change, which is considered one of the major drivers today that alter the pattern of biodiversity distribution, affect the ecosystem functioning and change the flows of ecosystem goods and services to be provided by a healthy ecosystem. In the paper, we first built a composite biodiversity indicator on the concept of Natural Capital Index so as to integrate information regarding the quantitative and qualitative changes of ecosystems driven by warming climate conditions. Furthermore, the composite indicator is integrated into the econometric specification so as to capture the marginal impacts of changes in biodiversity on the value of ecosystem goods and services due to climate change. The econometric problem is solved in a structural simultaneous system using three-stage-least-squares (3SLS) to analyze climate change impacts on forest ecosystems and the respective ecosystem service values across 17 European countries.

Keywords: 3SLS, composite biodiversity indicator, European forest ecosystem services, climate change impact

JEL: Q23, Q51, Q57

Note: An earlier version of this paper has been presented in the 2010 BIOECON conference in Venice and the Belpasso International summer school, held in Belpasso-Italy, 2010. Comments haven incorporated into this revision, which has been submitted to the 2011 EAERE conference in Roma, Italy

4.1 Introduction

Current model projections have consistently indicated that biodiversity would continue to decline over the 21st century, under different socioeconomic scenarios with trajectories of key indirect drivers of ecological changes, such as human population growth and greenhouse gas emissions (GHG) (Pereira *et al*., 2010; Leadley, *et al.* 2010). This in turn will impose threats to the benefits of future humanity and result in a change in our production and consumption patterns in the long run (Martens *et al*., 2003), as biodiversity underpins a variety of ecosystem services that are vital to human well-being.

Biodiversity by definition encompasses the variety of life on earth from genes to species, through to the broad scale of ecosystems across time and space. It is important in terms of determining the health of ecosystem, ensuring the stability and productivity of ecosystem, as well as contributing directly or indirectly to human wellbeing. In this regard, the term "biodiversity" is used largely as an assumed foundation for ecosystem processes, rather than simply the changing number of species on a species list. The relationship between biodiversity and ecosystem functioning or primary productivity has been of long-standing interest to ecologists (Kinzig *et al.*, 2001; Loreau *et al.*, 2001, 2002; Cameron, 2002). Over the past years, the subject has been researched in various ways: via experimental filed research, the formulation of mechanistic theories, and quantitative field observation, most of which have led to a common conclusion that a large variety of species has a positive influence on the productivity and stability of ecosystems, as greater biodiversity can cope with various circumstances in a given habitat and thus lead to the more efficient use of available natural resources (Martens et al, 2003; Loreau et al, 2001). Nonetheless, quantifying the link between biodiversity and ecosystem services remains a major scientific challenge to date (Pereira *et al.*, 2010), because there does not exist a general ecological relationship between ecosystem function and diversity owing to species-specific effects and important tropic links (Paine, 2002; Willims *et al.,* 2002). Certainly, biodiversity loss will negatively affect ecosystem functioning by changing the composition and distribution of species (Giller and O'Donovan, 2002; Schmid *et al.,* 2000; Bloger, 2001; Loreau *et al.,* 2001), which may have far-reaching socioeconomic consequences in the future, through the provision of ecosystem services to human society (Martens et al, 2003). Thus how to explicitly quantify the effect of biodiversity loss on human welfare has become a great challenge to the economists today.

In fact, the economics literature has shown many attempts to both conceptualize and value biodiversity, exploring the use of stated- and revealed- preference valuation methods, both of which intend to estimate the marginal impact of biodiversity loss on utility (Kontoleon *et al.,* 2007). These methods have been largely used to estimate the nonmarket values of biodiversity. On the other hand, biodiversity also have considerable market value through the supply of important inputs for economic production. Thus, the total value of biodiversity or ecosystems should encompass an array of ecosystems goods and services (EGS), including provisioning, cultural, regulating and supporting services, upon which human livelihoods depend (MEA, 2005; Chiabai *et al*, forthcoming; Ding *et al*, 2010). However, numerical analysis of the links between biodiversity and human well-being remains crude in the literature due to the complex non-linear relationship between biodiversity and ecosystem functioning and services. In this regards, only two studies have attracted our particular attention, both of which exploring the use of different biodiversity indicators, i.e. species richness and threatened flora and fauna indexes in modeling the effect of biodiversity loss in the value of ecosystem services or ecosystem productivity. The first refers to a recent study conducted by Costanza et al. (2007), who numerically demonstrated a positive relationship between species richness and net primary production (NPP) for the US., followed by Ojea et al. (2009), who employed the use of meta-analysis that has greatly extended their investigation from regional forest ecosystem valuation studies to a global scale. Nonetheless, our knowledge about the role of biodiversity in ecosystem functioning is very limited, using an individual biodiversity indicator might be able to explain partly (not sufficiently enough) the impacts of biodiversity loss on the value of ecosystem services and thus human welfare, but meanwhile it may also lose a lot of other important information as most of the biodiversity indicators deal with only one biodiversity attribute or a specific policy target. Therefore, the creditability of the estimates from the previous studies for aiding policymaking might be questionable.

For this reason, the present paper aims at contributing to bringing this gap by constructing a composite biodiversity indicator which integrates information about species changes (e.g. change in the abundance or distribution of populations), and ecosystem changes (e.g. change in extent of particular biomes) in a climate change context. Furthermore, we will run an econometric model to test whether the constructed composite biodiversity indicator is sensitive to a set of factors causing global changes, including the growth of population and economy, the land-use changes, and the rising earth's temperature. In particular, we are interested in testing whether global warming will have a substantial impact on the changes in biodiversity and ecosystem services, which will consequently influence the ecosystem benefits that human can receive in the future (interpreted as welfare changes to human beings), holding all other conditions constant. Data availability with regards to both biological species and economic values of the ecosystem services led our analysis focus on the forest ecosystems in Europe.

The organization of the article is as follows. Section 2 discusses the key assumptions of four different climate change scenarios and the respective impacts on the future patterns of biodiversity in Europe. Data regarding projections of socio-economic, ecologic and climatic conditions under future scenarios are also presented. Section 3 focuses on constructing a new composite biodiversity indicator for the study of climate change impact. Section 4 employs the use of three stages least squares (3SLS) model for testing the new composite biodiversity indicator and shows some preliminary results. Section 5 concludes.

4.2 The Future Pattern of Biodiversity in the Context of Climate Change

4.2.1 Climate scenarios for projecting the future trends of biodiversity

Scenarios do not predict the future, but rather paint pictures of possible futures and explore the various outcomes that might result if certain basic assumptions are changed. In order to explore the possible future biodiversity patterns in Europe, the scenarios used are based on the recent efforts of the IPCC (IPCC, 2000), which explore the global and regional dynamics that may result from changes at a political, economic, demographic, technological and social level. The distinction between classes of scenarios was broadly structured by defining them *ex ante* along two dimensions. The first dimension relates to the extent both of economic convergence and of social and cultural interactions across regions; the second has to do with the balance between economic objectives and environmental and equality objectives. This process therefore led to the creation of four scenarios families, namely A1, A2, B1 and B2 storylines, each of which contains a number of specific scenarios (IPCC, 2000). Hereafter, we call them IPCC scenarios throughout the paper. ***Table 1***. below summarizes the political, economic, demographic, technological and social assumptions made in each of the IPCC scenarios and analyzes their potential impacts on the future patterns of global biodiversity.

Table 1. IPCC scenarios of future global biodiversity patterns

Storyline	Key assumptions	Summary of major effects of the scenario	Impacts on biodiversity
A1 (offers an unfavorable perspective for biodiversity)	Slight population increase till 2050, then decrease; Very rapid economic growth; High level of income; A global mean increase in temperature of at least 4.4˚C (std 0.9) toward 2080; Forest area is stable due to increasing timber demand and recreational land use pressure. Significant conversion of agricultural land from food to bioenergy production.	Many pristine natural areas are converted into man-made areas; Costs of preserving natural areas are very high due to increase in land prices; Reduced ecosystem quality due to increased population densities, increased tourism, etc; Higher concentrations of GHG due to a substantial increase in energy use and land conversion	Patterns of bird and herptile species richness will not change dramatically; Plant and tree species richness will decrease in the southern part of Europe but increase in central and Scandinavian Europe.
A2 (offers a heterogeneous world)	Continually growing human population (15 billion by 2100); Slow economic growth; Economic development is primarily oriented and uneven; Regional self-reliance in terms of resources; Weak global environmental concern; Total consumption of natural resources is considerable; A global mean increase in temperature of at least 3.5˚C (std 0.7) toward 2080; Slightly decrease of forest area; Significant conversion of agricultural land from food to bioenergy production and human settlement.	Sharply increasing demand for foods, water, energy and land will result in a significant loss of natural ecosystems and species; Regional competition for good-quality natural resources will negatively affect the economic conditions in these countries and reduce attention for the preservation of natural resources; An increasing number of people will compete for a declining number of natural resources at the cost of quantity and quality of those remaining resources.	Patterns of bird and herptile species richness will not change dramatically; Plant and tree species richness will decrease in the southern part of Europe but increase in central and Scandinavian Europe.
B1 (offers a more favorable perspective for biodiversity)	A sharp reduction in arable farming and cattle breeding acreage due to a strong increase in productivity; The estimated temperature increase is about 2.7˚C (std 0.6) toward 2080; Pressure from population growth is considerably lower; Forest area increases. Significant conversion of agricultural land from food to bioenergy production and human settlement.	A lot is done to improve ecological capital and therefore reduce threatening factors and prospects for biodiversity; Cropland production is concentrated in optimal locations; Grassland is protected by policy.	Natural ecosystems are less affected both in quantity and quality
B2 (very locally concentrated social, economic and ecological problems)	The pressure on natural system is greatly reduced due to high average education levels and high degree of organization within communities; Stable population; Relatively slow economic development; Regionally and locally oriented environmental policies are successful; A global mean increase	The general picture of biodiversity in the future largely depends on the introduction of socio-economic policies that support local and regional initiatives to achieve structural solutions.	Hard to estimate global biodiversity trend due to the high heterogeneity

	in temperature of at least 2.0˚C (std 0.7) toward 2080; Land-use changes from food to bioenergy production or forestry.

Source: adapted from Martens et al. (2003) and ATEAM model assumptions

Scenario A1 and A2 represent the degree of economic convergence and of social and cultural interactions across regions, but are distinguished in terms of the scale of socio-economic interactions. Scenarios A1 focuses on a global perspective, in which biodiversity will receive extra pressure from the expected high growth rates in global economy and world population. In this scenario, many pristine natural areas will be converted to man-made areas to meet the increasing consumption demand. Thus land prices will be driven up as well as costs of preserving natural habitats, which may directly affect biodiversity quantity. Moreover, increased energy use and land conversion will contribute to higher concentrations of greenhouse gases (GHG) in the atmosphere and reduce biodiversity quality. This scenario also considers different combinations of fuel, referring to scenario A1F1 in the IPCC report. Scenario A2 represents a heterogeneous world differentiated into a series of consolidated economic regions characterized by low economic, social, and cultural interactions, uneven economic growth and large income gap between industrialized and developing countries. Under this scenario, a continually growing population will lead to a sharp increase in demand for foods, water, energy and land and result in significant loss of natural ecosystems and species. Moreover, low technological improvement in production will increase the pressure from pollution, which will affect the quality of biodiversity. Finally, the fragmentation of local infrastructures also implies conflicts between scarce resources and increasing number of people, as the latter will have to compete for a declining number of natural resources at the costs of quality and quantity of whose remaining resources.

On the contrary, the B-type scenarios depict a world, where economic objectives and environmental and equity objectives are more balanced. From a global sustainability perspective, Scenario B1 shows that environmental and social consciousness can be combined in a more sustainable development manner, offering a more favorable perspective for biodiversity than the A-type scenarios. Moreover, technological development is expected to shift towards renewable energy and higher productivity and consequently reduce the pressure on natural ecosystems from decreased pollution and land conversion. Finally, biodiversity will also benefit from lower pressure of global population growth and improved ecological capital. Similarly to scenario B1, the B2 scenario is environmentally oriented with a focus on both environmental and social sustainability, but locally oriented. In this scenario, average education level and degrees of organization within communities are high and energy and material efficiency can be achieved. All these social and technological achievements can reduce the pressure on natural ecosystem. However, it is difficult to predict a global trend of biodiversity due to the large regional difference, including socio-economic policies that support land and regional initiatives.

4.2.2 Data: projections under the IPCC Storylines

Under different IPCC storylines, projections have been developed to describe possible outcomes of different political, economic, demographic, technological and social assumptions for the future development. These include the projected trends of GDP, population, incremental temperature, ecosystem productivity, distribution of species and so on, subject to the changes in a set of key assumptions on which the IPCC storylines are based (see Table 1). In this study, we explore the use of climatic, socio-economic and ecological projections to investigate the pressure on biodiversity and to quantify the consequent quality and quantity changes of terrestrial biodiversity following four future development paths. As for the scale of the study, only 17 European countries are taken into account due to the limited data availability regarding number of biological species projected under climate change scenarios. In addition, empirical evidence has shown that the impacts of changing climate conditions are highly spatially heterogeneous, as organisms, populations and ecological communities do not respond to approximated average of global warming (Walther *et al.*, 2002). To account for regional climate differences, we further divide the 17 European countries into 3 geo-climatic clusters, namely Mediterranean Europe (Greece, Italy, Portugal, Spain), Central North Europe (Austria, Belgium, France, Germany, Ireland, Luxembourg, Netherlands, Switzerland, United Kingdom), and Scandinavian Europe (Denmark, Finland, Norway, Sweden), where similar climatic patterns and taxa might be identified.

The data used are independently published by a number of IPCC data distribution centers across the world for 2050, downscaled at country level. The demographic and economic trends represented by the future per capita GDP, population density are projected and distributed by the Center for International Earth Science Information Network (CIESIN, 2002) at Columbia University. The annual mean temperature was projected by the Tyndall Centre in the UK (www.tyndall.ac.uk), which combined the use of Global Circulation Models/SRES (including CGCM2, CSIRO2, HadCM3 and PCM) to estimate the possible increase of temperature in degrees Celsius for each country under different IPCC scenarios. The biophysical changes of biodiversity comprises the quantitative change measured in terms of changes in the area of forest habitat, and the qualitative change indicated by changes in the number of terrestrial species (including plant, tree, bird and herptile). The future trends of these changes under IPCC scenarios are projected in the frame of the Advanced Terrestrial Ecosystem Analysis and Modelling (ATEAM) project (Schroeter, et al. 2004). In particular, species richness under current and future conditions are projected taking into account total 383 bird species, 108 reptile and amphibian species, 1350 plant species and 125 tree species appeared in the EU. To keep the consistency across a large range of data sources, we derive all data from projections that represent a combination with the HadCM3 model.

Our knowledge about to what extent biodiversity can respond to climate change is limited and the quantification of associated economic gains or losses to human welfare cannot be straightforward but through valuing biophysical changes of ecosystem services under future climate conditions. In this study, values of ecosystem goods and services provided by the European forests are taken from Ding *et al.* 2010, who provided detailed projections of ecosystem values following four future IPCC storylines vis-à-vis to the baseline year of 2000. The valuation exercises were conducted separately for three types of ecosystem services defined in Millennium Ecosystem Assessment, i.e. provisioning, regulating and cultural services (MEA, 2005). More specifically, forest provisioning services contain the benefits derived from the production of timber and other wood forest products, regulating services provides non-monetary benefits from CO2 sequestration in the forest, and cultural services provides humans with direct incomes from the related tourism industries and non-monetary benefits from the enjoyment of existing forests. The market or non-market nature of different values of ecosystem services determined the use of various valuation methods and also indicated different degrees of biodiversity dependence. To capture the specific marginal effect of biodiversity on each ecosystem service, we keep the three types of values separately rather than using a summed total ecosystem value. All values were first projected to 2050 and then adjusted to 2005 US$[24].

4.3 The Construction of Simple Composite Biodiversity Indicator

The greatest challenge that scientists are facing today is to develop appropriate biodiversity metrics so as to measure and monitor the different dimensions of biodiversity and to predict the future trends of biodiversity and ecosystems. Moreover, these biodiversity measures should also be able to compass essential biological information, incorporate socioeconomic impacts, as well as guide policy interventions towards more effective biodiversity management. To this extent, the existing biodiversity data will be useful for developing quantitative scenarios of the future trajectories of biodiversity (Pereira *et al.*, 2010). From a methodological perspective, there is a

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[24] For valuation details and results, readers are recommended to refer to Ding *et al* (2010).

general need of creating a workable "calculus" of biodiversity that allows not just global summation, but also estimation of the more localized marginal gains and losses from global changes induced by socioeconomic development and land use changes in different places (Faith, 2005). These measures are therefore compatible with trade-offs and synergies in regional planning.

4.3.1 Why composite indicator?

Biodiversity indicators are developed for various purposes. By far, a long list of biodiversity measures has been developed to reflect a range of attributes and issues of concern. At global level, there are roughly 40 potential measures being developed for the Convention on Biological Diversity (CBD) and about 26 indicators being considered in the Streaming Biodiversity Indicators in Europe 2010 process (Mace and Baillie, 2007). Nevertheless, for the purpose of public and business decisions and as an effective communication tool to broader audience, a single, simple or composite biodiversity measure might be more influential, just like the use of Gross Domestic Production (GDP) in economic analysis and the Dow Jones indicator in stock market (Mace and Baillie, 2007; Balmford, *et al.* 2005). There are now a number of composite indicators have been developed. For example, the Natural Capital Index (NCI) is constructed as a weighted sum of the product of the extent of each ecosystem (relative to a baseline) with the condition of the ecosystem, where the condition is measured as the population size of a group of indicator species relative to a baseline (ten Brink, 2000). A similar indicator is the Biodiversity Intactness Index (BII) recently developed by Scholes and Biggs (2005), which also takes into account different ecosystems being weighted by their species richness and population size being estimated for each land-use class in each ecosystem. Apparently, the latter requires more detailed information of species under each type of land-use. Given the limited data availability, we therefore propose to adopt the NCI approach to construct a similar composite indicator for analyzing climate change impacts on the biodiversity and ecosystem services in Europe.

NCI framework considers biodiversity as a natural resource containing all species with their abundance, distribution, and natural fluctuations. Human direct and indirect interference may affect ecosystem size (through land conversion) and exert pressures on ecosystem quality (such as over-exploitation and fragmentations). As a result, both decreased ecosystem quantity and quality will lead to the loss of biodiversity. In this context, the development of NCI framework aims at providing a quantitative and meaningful picture of the state of and trends in biodiversity to support policymakers in a similar way as GDP, employment and Price Index do in economics.

Moreover, the structure of NCI also allows the analysis of socio-economic scenarios on their effect on biodiversity. In technical terms, NCI is the product of changes in the size of ecosystems (*"ecosystem quantity"*) and the changes in abundance of a core set of species (*"ecosystem quality"*) within the remaining ecosystem, where both quality and quantity are expressed relative to an "optimal" or "intact" baseline (ten Brink, 2000).

Equation of the NCI:

NCI = ecosystem quality (% of species abundance) × *ecosystem quantity (%* area of the country*)*

Thus, the state of biodiversity and process of ecosystem degradation with respect to a baseline in a given policy context can be visualized using NCI – see ***Figure 1***.

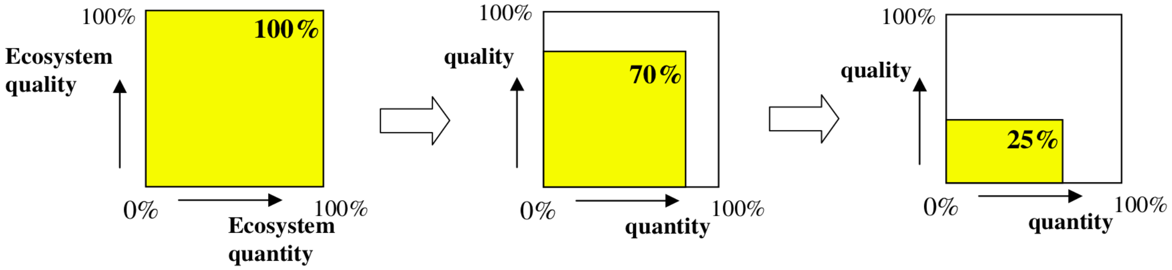

Figure 1. Trends of ecosystem quality and quantity using NCI (Source: Ten Brink (2007) pp.2)

The NCI chooses the use of less modified "pre-industrial baseline" so that major anthropogenic impacts on the changes of biodiversity quality (e.g. loss of species abundance) and quantity (e.g. loss of natural habitat) can be observed and compared. The NCI score ranges from 0 to 100% representing an entire deteriorated (0%) and intact ecosystem (100%), respectively. It summarizes the extent to which a landscape has preserved its original (baseline) natural capital and enables the analysis of biodiversity effects in different socio-economic scenarios. Obviously, one of the advantages of the NCI is that it allows us to aggregate many biodiversity parameters to a few or perhaps a single, more or less representative biodiversity index for the entire ecosystem (ten Brink, 2000).

4.3.2 Construct an aggregated NCI-like biodiversity composite indicators for the IPCC scenarios

To project the trends of biodiversity under future climate change pressure and their respective socio-economic impacts, it is impossible to use individual biodiversity indicators, such as species richness or abundance of a certain species, due to our limited knowledge about how individual species responds to an increase in temperature or precipitation rate and what are the consequences on ecosystem functioning and performance. Rather, a simple composite indicator similar to the NCI is ideal since it is designed in a way that biodiversity loss can be linked to socio-economic drivers as well as other anthropogenic impacts, including degradation of natural habitats, land-use changes and climate change. Moreover, it also aggregates information from a set of core species, such as tree, plant, bird, herptile, which determine together the overall ecosystem quality. Therefore, the future trends of ecosystem quality and quantity under different climate change scenarios can be assessed with respect to a selected baseline.

Subject to restrict data constraints, we set up our baseline year at 2000 and the policy target at 2050. This period is characterized as post-industrialization era, in which many stringent environmental policies have been successfully implemented among the most developed European economies, in terms of pollution reduction, sustainable resource management and promoting green economy. Thus, in our dataset, many countries are projected to have a stable increase in either forest area or increased richness of many species or both. Therefore, the original NCI score range ([0-100%]) cannot apply, if we allow for an overall improvement of the forest ecosystems in some countries. Instead, we set up two intervals to indicate the state of the forest ecosystem under different future scenarios: (1) [0-100%] indicates a degradation of ecosystem quantity and/or quality; (2) [100%-200%] indicates an improved ecosystem states. We acknowledge the limitations of selecting a baseline year very close to the policy target, as the rather short time span will not allow for a significant variation of species richness across different climate change scenarios, unless there is an unexpected dramatic climate shock causing extinction of a large number of species. Also, an increase in species richness may not imply an increase in the environmental quality, but may be caused by adding invasive species that are damages to the local ecosystem. Nonetheless, our calculation can still be useful in the context of policymaking, especially when immediate decisions need to be made for preventing endangered species from extinction under warming weather conditions or when appraisals are required for projects that may affect interactions between climate change and ecosystem services.

In the present study, a NCI-like indicator is constructed to describe the change of overall ecosystem under different IPCC scenarios. Similar to the NCI approach, ecosystem quality is calculated as ratio between projected species richness of different future storylines in 2050 and that of the baseline year 2000. The ecosystem quality contains information of four core species, including tree, plant, bird and herptile for the selected 17 European countries. Ecosystem quantity is the percentage of forest habitat in a country's total area. Figure 2 presents a flow chart showing how the NCI-like biodiversity indicator is constructed.

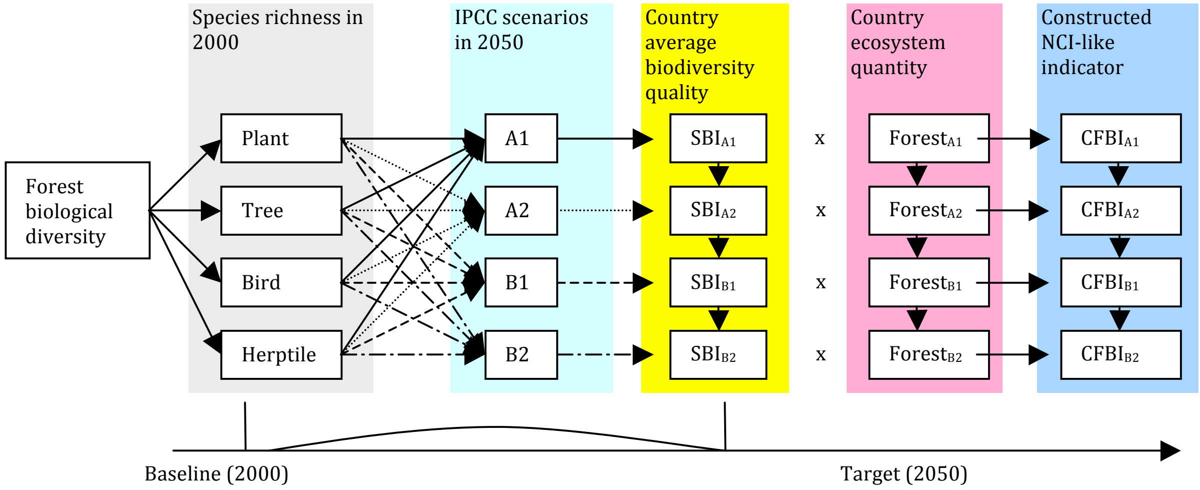

Figure 2. Constructing a NCI-like indicator to estimate the trend of biodiversity in future IPCC scenarios (note: SBI refers to the aggregated average score of species richness of plant, tree, bird and herptile species.)

The construction of aggregated NCI-like indicator encompasses two steps.

The ***first step*** is to compute the average changes of ecosystem quality in the future under different climate change scenarios. For each country, the change of individual species under future climate change scenarios is expressed as the ratio between species richness of the species in 2050 and that of the baseline. Furthermore, we aggregated individual percentage changes of species richness for tree, plant, bird and herptile to get a country average score, which describes the changes of country's ecosystem quality under each IPCC scenario with respect to the baseline.

The ***second step*** is to construct a NCI-like indicator, a composite indicator, which aggregates information regarding future qualitative and quantitative changes of biodiversity with respect to the baseline. We name it as Composite Forest Biodiversity Indicator (CFBI), which is the product of percentage changes of forest quality (calculated in step 1) and the percentage changes of forest area in 2050 with respect to the baseline under different IPCC storylines. Thus, the computed

CFBI score also reflects the direct impacts of land-use changes on biodiversity. In particular, the expansion of forest area in many parts of Europe may have a positive impact on the CFBI score.

The calculated *CFBI* scores for the EU-17 under four different IPCC scenarios are presented in Figure 3 below.

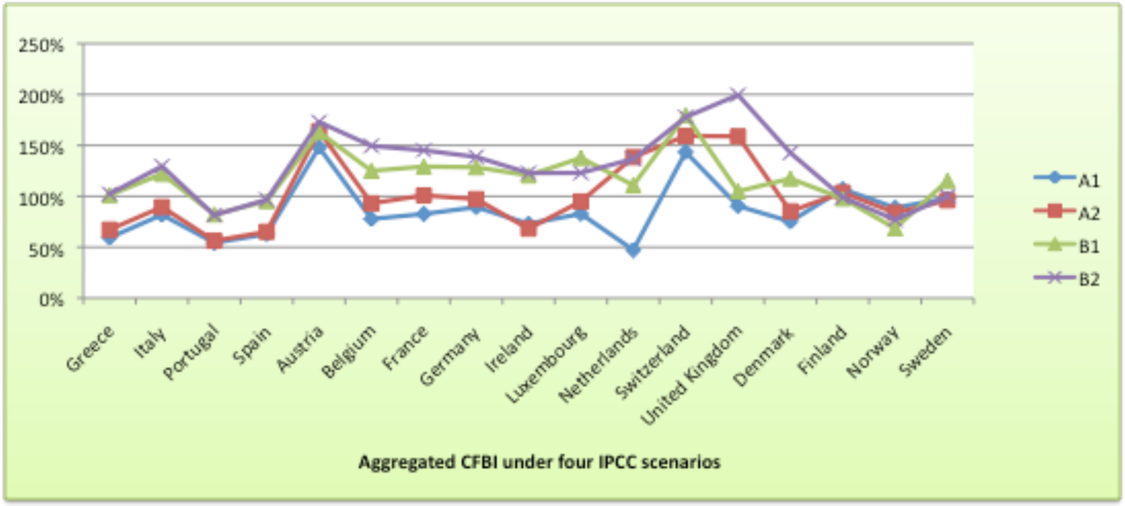

Figure 3. Computed CFBI score for the EU-17 under four IPCC storylines.

As we have mentioned above, the CFBI score ranges between two intervals: [0-100%] and [100%-200%]. If the *CFBI* falls between [0, 100%], it illustrates that a country's forest ecosystem has deteriorated under climate change scenarios because of the reduction of forest area as a result of land use competition for economic development, and/or because of the decreased quality of biodiversity in the country, or because of a combination of the both causes. If the *CFBI* score falls between [100%-200%], it shows on average an overall improved forest ecosystem. However, the reason of such improvement is not straightforward. It may not be necessarily caused by the increase in species richness of the selected four species in the next decades, but may be due to the extended ecosystem coverage as a result of some effective environmental policy regimes of the country, such as increased forest area due to reforestation activities. Moreover, it is also important to note that a *CFBI* score greater than 100% does not necessarily mean the local species are not under threats, rather it indicates an overall improvement of the ecosystems due to compensation between different aspects of biodiversity. Thus, to better interpret the *CFBI* score, we need to look closely at the national/regional forest management policies and their effectiveness.

In Figure 3, the CFBI score shows that if moving towards the economic oriented development paths, as represented by the A1 and A2 scenarios, we will most likely observe a worsen status of forest ecosystem across Europe owing to increased pressures from economic development, population growth, severer increase of average temperature and land-use conversion. Among all others, the warmer region, i.e. Mediterranean Europe suffers the most loss of biodiversity quantity and quality in both scenarios compared to the colder regions. On the contrary, the environmental oriented development paths, as represented by B1 and B2 scenarios, show a significant improvement in the forest status in most of the European countries, except Greece, Portugal, Spain, Finland, Norway and Sweden. This implies that the adoption of sustainable forest management practices in Europe is successful in general. However, given the relatively high reference level of forest management in the Scandinavian countries in the baseline year, we will not foresee significant improvement in forest quantity and quality over the next 40 years, independent from the future standpoints. Whereas in the Mediterranean countries, although the resources management in practice are considered less efficient than those of Northern European countries, we can still observe a general improvement of the forest status owing to the sustainable management of natural resources, slowing down population growth, improving sectoral productivities and energy efficiency, and reducing land conversion.

4.4 The Econometric Model

4.4.1 The hypotheses and model specification

It is assumed that climate change disturbance through biodiversity and ecosystem functioning will impose an impact, most probably a negative one, on human welfare, the objective of our model is therefore to explicitly assess this complex interaction and then estimate the marginal effects of climate change induced biodiversity loss on the value of ecosystem services. This assumption implies a number of hypotheses that we would like to test using the econometric model:

(1) *Climate change, here expressed as increase in temperature, will alter the pattern of biodiversity distribution and species richness presented in a geographical region, which is measured by the composite forest biodiversity indicator (CFBI). In particular, we want to test whether increases in temperature will have effects over the biodiversity indicators that are ecosystem service specific and spatially different.*

(2) *The climate change induced CFBI changes will further affect the ecosystem's ability of providing goods and services and their respective values. Similarly, this effect is also expected to vary across geo-climatic regions and the types of ecosystem services under consideration.*

To capture the complex relationships between biodiversity, ecosystem and human welfare, we propose to solve the problem in a simultaneous equation system using 3SLS (three-stage-least-squares) regression, which is considered consistent and more efficient than a linear approximation in this respect (Verbeek, 2000). In particular, the simultaneous structural system contains following three equations:

Eq. (1)

$$ln(EV_i) = \beta_{10_i} + \beta_{11i} ln(fa) + \beta_{12i} ln(t) + \beta_{13i} CFBI + \beta_{14i} CFBI\_t + \varepsilon_{11i}$$

Eq. (2)

$$ln(fa) = \beta_{20} + \beta_{21} ln(GDP) + \beta_{22} ln(t) + \beta_{23} ln(pop\_dens) + \varepsilon_{21}$$

Eq. (3)

$$CFBI = \beta_{30} + \beta_{31} t + \beta_{32} t^2 + \beta_{33} nts + \beta_{34} nbs + \beta_{35} nps + \beta_{36} nhs + \beta_{37} ln(pop\_den) + \beta_{38} ln(GDP) + \varepsilon_{31}$$

w*here*

CFBI = Composite Forest Biodiversity Indicator (%)
t = increased Celsius degrees of local temperature by 2050 under future IPCC scenarios
fa = projected forest area (million ha) in 2050 under future IPCC scenarios
Pop_dens = projected population density (heads/ha) in 2050 under IPCC scenarios
GDP = projected gross domestic production (billion $) in 2050 under IPCC scenarios
EV = economic value of ecosystem service *i* (in million $) estimated for 2050 under IPCC scenarios
nts = number of tree species projected in 2050 under IPCC scenarios
nbs = number of bird species projected in 2050 under IPCC scenarios
nps = number of plant species projected in 2050 under IPCC scenarios
nhs = number of herptile species projected in 2050 under IPCC scenarios

We assume that *EV, CFBI and fa* are endogenous variables in the system and ε_1, ε_2 and ε_3 are the stochastic disturbance terms that capture all unobservable factors that may influence the dependent variables. In the first two equations, all variables, except *CFBI* are in their log-transformations indicate that the estimated beta coefficients measure the elasticity of dependent variables with respect to the changes in a set of explanatory variables. As for the warming impact on biodiversity, it is estimated using equation (3) by regressing *CFBI* on temperature variables (t *and* t^2), along with other biological and socio-economic variables that may explain the trends of biodiversity changes in the future scenarios. In particular, the temperature variable t will capture the marginal impact of climate change on biodiversity with increment of 1ºC in the temperature and the *squared t* is introduced to capture the rate of this change. In Table 2, we summarize the descriptive statistics of all the variables. For each variable, we have four observations under four IPCC storylines for total 17 countries under consideration, which gives rise to total 68 observations.

Table 2. A statistic summary

Variables	Obs	Mean	Std. Dev.	Min	Max
Forest area (fa)	68	7.02	7.36	0.07	25.88
Population density (pop_dens)	68	1.24	1.02	0.08	3.33
GDP	68	1110.28	1310.00	22.38	5569.02
Number of tree species (nts)	68	38.42	13.51	10.96	70.96
Number of bird species (nbs)	68	130.26	13.58	106.47	154.31
Number of plant species (nps)	68	259.64	36.52	199.61	361.78
Number of herptile spcies (nhs)	68	20.00	11.04	1.72	39.39
The composite biodiversity indicator (cfbi)	68	1.08	0.34	0.47	2
Temperature (t)	68	3.69	1.22	1.5	6.9
Economic value of provisioning services (EV_{PS})	68	4776.07	5214.79	100.95	17600
Economic value of cultural services (EV_{CS})	68	454.07	568.80	3.13	2615.14
Economic value of regulating services (EV_{RS})	68	2041.77	2023.33	71.39	7465.75

Next, we proceed with a 3SLS regression which allows us to estimate simultaneously (1) the determinants of economic value of ecosystem services; (2) the determinants of land-use changes (i.e. the changes of forest land cover); (3) the determinants of changes in biodiversity.

More specifically, in Equation (1), we attempt to explain the economic value of ecosystem services as a function of forest area, increases of temperature and biodiversity conditions. We simultaneously test the hypotheses that enlarged forest area and improved biodiversity condition will positively affect the ecosystem values, whereas rising temperature may have a negative impact.

Equation (2) attempts to explain the land-use change, as expressed by the enlarged or shrunk forest area in the model, is mainly driven by socio-economic and demographics variables of the country. Especially, we expect that higher level of GDP generated in the EU member states in the future scenarios will drive the increase of demand for forest related products and services, in particular, in terms of an improved forest quality and increased forest coverage. Thus the desire for a better natural environment will trigger the reinforcement of sustainable management policies to conserve natural habitats and forest biodiversity. On the contrary, the mounting populations projected in future scenarios will increase the pressure on the natural area by converting natural forests to agricultural land or human settlement. In the meanwhile, we also assume that temperature may have a role in affecting the forest natural regeneration process, but direction of its impact on forest area is ambiguous.

Finally, Equation (3) attempts to test statistically whether the RHS variables, such as rising temperature, changes of species richness in a set of key species, and changes of socio-economic and demographic conditions under different climate change scenarios can influence the dependent variable *CFBI*, which measures the general improvement or degradation of biodiversity quality and quantity corresponding to each of the projected future states. Especially, we are interested in whether warmer conditions will negatively affect forest biodiversity across regions, as well as the ecosystem's ability of providing ecosystem goods and services and their respective values. Moreover, high population density and continual economic growth are expected to impose high pressure on biodiversity through intensive conversion of land from natural forests to other land-uses and therefore negatively affect biodiversity quality and quantity.

4.4.2 3SLS results

Given the baseline model specification above, we first run 3SLS regression in a global condition, in which all data are pooled together without considering the different spatial effects of climate change. Later, we will modify the baseline model in order to capture the specific impact of climate change on each of the three geo-climatic regions, i.e. Mediterranean Europe, Central Europe and Scandinavian Europe. However, due to the nature of ecosystem values varies depending on the types of ecosystem services under consideration, we shall treat the three types of values differently.

(1) Estimating the global effects using the baseline model

Table 3 below reports the 3SLS results of the baseline model. The goodness of the linear approximation in the structural simultaneous system was assessed based on the coefficients of determination (R^2). For almost all equations, the estimated R^2 (>0.5) with P>0.0000 suggest the goodness of fit of the performed regression. Independent from the type of ecosystem service, most of all estimated beta coefficients carry the expected sign.

Table 3. 3SLS results of the baseline model – global effects

Provisioning Service				**Cultural Service**				**Regulating Service**			
Eq.	"R-sq"	chi2	P	Eq.	"R-sq"	chi2	P	Eq.	"R-sq"	chi2	P
(1)	0.401	54.25	0.000	(1)	0.931	548.13	0.000	(1)	0.839	198.57	0.000
(2)	0.534	78.04	0.000	(2)	0.537	78.80	0.000	(2)	0.536	79.36	0.000
(3)	0.615	141.77	0.000	(3)	0.624	138.74	0.000	(3)	0.636	135.69	0.000
Equation (1)				Equation (1)				Equation (1)			
Dep. Var.: $lnEV_i$				Dep. Var.: $lnEV_i$				Dep. Var.: $lnEV_i$			
Var.	Coef.	z	P>|z|	Var.	Coef.	z	P>|z|	Var.	Coef.	z	P>|z|
lnfa	0.671	5.68	0.000	*lnfa*	1.060	22.19	0.000	*lnfa*	0.740	12.27	0.000
lnt	1.032	2.04	0.041	*lnt*	-0.664	-3.24	0.001	*lnt*	0.670	2.59	0.010
cfbi	2.299	3.94	0.000	*cfbi*	-0.895	-3.73	0.000	*cfbi*	1.202	3.97	0.000
Equation (2)				Equation (2)				Equation (2)			
Dep. Var.: *lnfa*				Dep. Var.: *lnfa*				Dep. Var.: *lnfa*			
Var.	Coef.	z	P>|z|	Var.	Coef.	z	P>|z|	Var.	Coef.	z	P>|z|
lnGDP	0.850	8.00	0.000	*lnGDP*	0.837	7.85	0.000	*lnGDP*	0.836	7.84	0.000
lnt	0.854	2.16	0.030	*lnt*	0.819	2.07	0.038	*lnt*	0.813	2.06	0.040
lnpd	-0.453	-3.65	0.000	*lnpd*	-0.539	-4.27	0.000	*lnpd*	-0.555	-4.40	0.000
Equation (3)				Equation (3)				Equation (3)			
Dep. Var.: *CFBI*				Dep. Var.: *CFBI*				Dep. Var.: *CFBI*			
Var.	Coef.	z	P>|z|	Var.	Coef.	z	P>|z|	Var.	Coef.	z	P>|z|
t	-0.492	-4.48	0.000	t	-0.519	-4.51	0.000	t	-0.494	-4.28	0.000
t^2	0.054	4.01	0.000	t^2	0.058	4.12	0.000	t^2	0.055	3.90	0.000
nts	0.016	5.03	0.000	*nts*	0.017	5.33	0.000	*nts*	0.020	6.20	0.000
nbs	0.004	1.72	0.085	*nbs*	0.001	0.45	0.653	*nbs*	-0.000	-0.02	0.986
nps	-0.001	-0.91	0.363	*nps*	-0.001	-0.60	0.548	*nps*	-0.001	-1.07	0.286
nhs	0.001	0.72	0.474	*nhs*	-0.000	-0.04	0.972	*nhs*	0.005	2.11	0.035
lngdp	0.022	1.01	0.311	*lngdp*	0.024	1.12	0.264	*lngdp*	0.032	1.46	0.145
lnpd	0.046	1.85	0.064	*lnpd*	0.022	0.86	0.391	*lnpd*	0.014	0.55	0.585
Nr. Of observations: 68 Endogenous variables: lnEV$_i$, lnfa, cfbi Exogenous variables: lnt, lngdp, lnpd, t, t^2, nts, nbs, nps, nhs											

In particular, in equation (1), it shows that the value of forest ecosystem services is statistically significantly related to the forest size. That is every additional hectare of forest will lead to proportional increases in values for all ecosystem services, and the marginal effects range from 67% on provisioning service to more than 100% on cultural service. Moreover, the estimated coefficients of biodiversity variable are statistically significant for all ecosystem services indicating a significant impact of biodiversity on the value of ecosystem services, however the direction of the impact is vague. For instance, the composite biodiversity indicator is found positive and statistically significantly correlated with the provisioning and regulating services, but cultural service. We suspect this is due to the fact that pooling data across geo-climatic regions may mess us the different spatial effects of climate change imposed on biodiversity at regional level. We shall treat this problem later in a modified regional model specification. Finally, as expected, all ecosystem values are found sensitive to the change of temperature. That is to say, every 1ºC increase in temperature will contribute proportionally to the changes of the value of ecosystem services. In particular, the impact of rising temperature is positive on the value of provisioning and regulating services may be corresponding to the scientific discovery that the changing climate can increase forest productivity and also carbon stock in the boreal forest ecosystem in Scandinavian Europe at least in the short run (Garcia-Gonzalo et al., 2007). Nevertheless, the warming condition will negatively decrease the cultural value provided by European forests as a whole due to the diminishing cultural value generated in Mediterranean forests, where higher recreational values are usually found, as these forests will suffer from warming temperature and lower precipitation rate.

Furthermore, Equation (2) shows that all selected explanatory variables are statistically significantly related to land-use changes. The estimated coefficients of each variable are found similar across all ecosystem services, suggesting the robustness of our results. Our results suggest that increases in GDP and rising temperature contribute proportionally to the extension of forest areas. As argued previously, our desire for a better natural environment is increased along with our growing wealth, whereas the positive impact of climate change on forest area may imply the effectiveness of sustainable forest management practices that promote deforestation activities and encourage the enlarged plantations in most of the EU-17 countries. Finally, the negative coefficients of population density under all ecosystem services indicate the mounting population in the future state will impose greater pressure on forest land and may lead to the conversion of protected forest area to other land uses such as human settlement.

Finally, in Equation (3), we detect clearly a negative impact of rising temperature on the composite biodiversity indicator at increasing rate. In other words, our finding suggests that forest biodiversity is already suffering from the warm temperature in Europe and the continual changes in temperature will worsen the situation. Moreover, the beta coefficients of temperature variables are found consistent across ecosystem services, suggesting the robustness of our results. In addition, the increase of every additional tree species, among other things, contributes proportionally to 1% increase in the score of the composite biodiversity indicator. In contrast, the richness of other species is not statistically correlated with forest biodiversity indicator, so as the two socio-economic variables (GDP and population density).

(2) Estimating the regional effects using a modified model specification

In order to further test the hypothesis that climate change imposes different regional effects on biodiversity indicator and thus the respective value of ecosystem services, i.e. the climate change induced biodiversity effect on ecosystem service values, we introduce a cross-effect between *CFBI* and regional temperature variables to generation a matrix of $CFBI\_T_{region}$ that contains three regional specific *CFBI* variables and substitute *CFBI* in Equation (1) with this new matrix. This is to capture the indirect impact of climate change on the value of ecosystem services. Furthermore, we modify Equation (3) by substituting the temperature variable with a matrix of regional temperature variables, t_{region}, which allows us to differentiate impacts of rising temperature at different geographical locations. As a result, we obtain a modified structural simultaneous system below. Now, we will repeat the regression analysis using 3SLS in this modified structural system.

Eq. (4)

$$ln(EV_i) = \beta_{10_i} + \beta_{11i}ln(fa) + \beta_{12i}ln(t) + \beta_{13i}CFBI\_T_{region} + \varepsilon_{11i}$$

Eq. (5)

$$ln(fa) = \beta_{20} + \beta_{21}ln(GDP) + \beta_{22}ln(t) + \beta_{23}ln(pop\_dens) + \varepsilon_{21}$$

Eq. (6)

$$CFBI = \beta_{30} + \beta_{31}t_{region} + \beta_{32}t^2 + \beta_{33}nts + \beta_{34}nbs + \beta_{35}nps + \beta_{36}nhs + \beta_{37}ln(pop\_den) + \beta_{38}ln(GDP) + \varepsilon_{31}$$

The 3SLS regression results are presented in Table 4. The goodness of the linear approximation in the structural simultaneous system was assessed based on the coefficients of determination (R^2). Comparing to the baseline model, we see that the introduction of regional effects improves significantly the goodness of fits of the performed regression. Moreover, the new model result again shows that one-hectare increase of forest area is statistically significantly correlated to every one-dollar increase in the value of all ecosystem services.

Table 4. 3SLS results of the modified model – regional effects

Provisioning Service				**Cultural Service**				**Regulating Service**			
Eq.	"R-sq"	chi2	P	Eq.	"R-sq"	chi2	P	Eq.	"R-sq"	chi2	P
(1)	0.582	111.16	0.000	(1)	0.985	3704.47	0.000	(1)	0.874	345.85	0.000
(2)	0.533	77.07	0.000	(2)	0.537	79.38	0.000	(2)	0.537	79.37	0.000
(3)	0.643	154.25	0.000	(3)	0.643	152.49	0.000	(3)	0.642	157.07	0.000
Equation (4)				Equation (4)				Equation (4)			
Dep. Var.: $lnEV_i$				Dep. Var.: $lnEV_i$				Dep. Var.: $lnEV_i$			
Var.	Coef.	z	P>|z|	Var.	Coef.	z	P>|z|	Var.	Coef.	z	P>|z|
lnfa	0.863	8.19	0.000	*lnfa*	1.011	43.18	0.000	*lnfa*	0.769	13.50	0.000
lnt	0.193	0.41	0.680	*lnt*	-0.290	-2.77	0.006	*lnt*	-0.156	-0.62	0.536
cfbi_ts	-0.041	-0.27	0.786	*cfbi_ts*	-0.059	-1.74	0.082	*cfbi_ts*	0.085	1.04	0.296
cfbi_tm	-0.493	-2.50	0.012	*cfbi_tm*	0.279	6.31	0.000	*cfbi_tm*	0.251	2.38	0.018
cfbi_tc	0.062	0.57	0.571	*cfbi_tc*	-0.027	-1.10	0.272	*cfbi_tc*	0.259	4.38	0.000
Equation (5)				Equation (5)				Equation (5)			
Dep. Var.: *lnfa*				Dep. Var.: *lnfa*				Dep. Var.: *lnfa*			
Var.	Coef.	z	P>|z|	Var.	Coef.	z	P>|z|	Var.	Coef.	z	P>|z|
lnGDP	0.844	7.94	0.000	*lnGDP*	0.846	7.93	0.000	*lnGDP*	0.838	7.89	0.000
lnt	0.859	2.18	0.030	*lnt*	0.821	2.08	0.038	*lnt*	0.820	2.08	0.038
lnpd	-0.446	-3.56	0.000	*lnpd*	-0.524	-4.14	0.000	*lnpd*	-0.532	-4.26	0.000
Equation (6)				Equation (6)				Equation (6)			
Dep. Var.: *CFBI*				Dep. Var.: *CFBI*				Dep. Var.: *CFBI*			
Var.	Coef.	z	P>|z|	Var.	Coef.	z	P>|z|	Var.	Coef.	z	P>|z|
ts	-0.536	-4.68	0.000	*ts*	-0.538	-4.70	0.000	*ts*	-0.503	-4.46	0.000
tc	-0.513	-4.40	0.000	*tc*	-0.514	-4.40	0.000	*tc*	-0.483	-4.19	0.000
tm	-0.575	-4.73	0.000	*tm*	-0.578	-4.76	0.000	*tm*	-0.553	-4.61	0.000
t^2	0.061	4.27	0.000	t^2	0.061	4.29	0.000	t^2	0.057	4.07	0.000
nts	0.017	5.11	0.000	*nts*	0.017	5.11	0.000	*nts*	0.018	5.44	0.000
nbs	-0.001	-0.43	0.669	*nbs*	-0.001	-0.60	0.550	*nbs*	-0.001	-0.65	0.513
nps	-0.000	-0.42	0.674	*nps*	-0.000	-0.38	0.702	*nps*	-0.001	-0.57	0.570
nhs	0.007	1.73	0.083	*nhs*	0.007	1.72	0.086	*nhs*	0.009	2.11	0.035
lngdp	0.035	1.56	0.119	*lngdp*	0.037	1.64	0.102	*lngdp*	0.038	1.69	0.091
lnpd	-0.008	-0.28	0.781	*lnpd*	-0.018	-0.57	0.566	*lnpd*	-0.022	-0.71	0.477

Nr. Of observations: 68
Endogenous variables: $lnEV_i$, lnfa, cfbi
Exogenous variables: lnt, cfbi_ts, cfbi_tm, cfbi_tc, lngdp, lnpd, ts, tc, tm, t^2, nts, nbs, nps, nhs

As for the spatial effects of climate change, our results are promising. First of all, three new explanatory variables *cfbi_ts, cfbi_tm and cfbi_tc* are introduced in Equation (4) to count for the indirect/induced impacts of climate change on ecosystem service values through the altered biodiversity across three geo-climatic regions: i.e. the Scandinavian Europe, Mediterranean Europe, and Central-Northern Europe, respectively. By comparing these coefficients with the coefficient of *lnt,* which captures the direct effects of rising temperature on the value of ecosystem services, we can better understand the dimensions and strength of the cross-effects that affect the ecosystem service values. Moreover, regional temperature effects on biodiversity are captured by the introduction of three temperature variables *ts, tm and tc* in Equation (6), with represent to temperature changes in the Scandinavian Europe, Mediterranean Europe, and Central-Northern Europe, respectively. These results are particularly useful for interpreting the cross-effects of biodiversity and temperature in Equation (4) and understanding the climate change induced biodiversity effect on the overall value of ecosystem services. In general, our results show that changing climate will accelerate biodiversity loss across all three geo-climatic regions (see the results of equation (6)), and these changes may impose even further impacts on the values of all ecosystem services provided by different forest ecosystems (see the results of equation (4)), but the directions and magnitudes of these impacts are mixed, depending on the nature of the ecosystem services under consideration. All in all, we can observe two opposite cross-effects of biodiversity and temperature on the value of ecosystem service values.

On the one hand, our results reveal that biodiversity and temperature are "complimentary" factors affecting the supply of EGS in a given geo-climatic region, and therefore for this region the climate change induced biodiversity loss may increase the overall negative impacts. This is particularly clear in the case of provisioning services provided by Mediterranean forests. Our results suggest that the negative impacts of climate change on biodiversity will go against the positive direct climate change impact on the Mediterranean forests, and generate a net negative impact on total value of provisioning services in the future. More specifically, biodiversity loss caused by increment of 1ºC in the temperature is responsible for at least 49% in every one-dollar reduction of the value of forest provisioning service in the Mediterranean forests. This finding is consistent with some of the previous studies. For instance, Linder *et al.* (2008) has found that climate change may reduces the forestry productivity in the Mediterranean region in the future, as warming will be greatest over western and southern Europe in summer, substantially affect the precipitation rate and increase the risk of extreme weather events, such as prolonged drought, storms and floods in the area. Moreover, in a different geographical context, Costanza *et al.* (2007) also found a strong positive relationship between biodiversity and ecosystem productivity in higher temperature regimes in the United States. However, the cross-effects of biodiversity and temperature are not statistically significant for the remaining two geo-climatic regions. To better understand the underlying reasons of this result, further investigation is needed.

On the other hand, biodiversity and temperature can also serve as "substitute" factors that determine some of ecosystem service values under consideration. This is to say, the climate change induced biodiversity impacts on EGS may attenuate/decrease the negative direct climate change impact in some regions, where biodiversity plays a key role in mitigating the those negative impacts of climate change. For instance, this is clear for the cultural services provided by the Mediterranean forests, in which the reduction of 1ºC in the temperature is responsible for half of every 1% improvement of biodiversity indicator score. The latter will consequently contribute to nearly 28% of every additional one-dollar value generated in the cultural services provided by Mediterranean forests. Similar result is found also for the regulating services in the region, where biodiversity richness is expected to have a significant role in determining the respective values. In conclusion, our result suggests that although climate change may have directly negative impacts on the value of ecosystem services, it is possible to mitigate these negative impacts by better managing biodiversity and natural resources. In many cases, the benefits derived from biodiversity can be large enough to compensate the loss of ecosystem productivities and values as a result of climate change.

4.5 Concluding Remarks and Further Research

This paper attempted to model the relationships between climate change, biodiversity and the value of ecosystem services with a specific emphasis on the climate change included biodiversity effects in European forests. The research begun with the construction of a composite biodiversity indicator that integrated quantitative and qualitative changes of biodiversity projected under different future climate scenarios. This indicator incorporated in-depth socio-economic reasons of biodiversity changes, along with climate change impacts was expected to be a simple but comprehensive biodiversity measure to analyze the climate change induced biodiversity effects and the resulting socio-economic impacts. In the present study, we tried to make the best use of existing data released by a large number of IPCC data distribution centers, regarding the projected trends of population growth, economic development, future species richness and increase in local temperature under different future climate scenarios. Values of ecosystem services were derived from a most recent assessment study on the climate change impacts on forest ecosystems in Europe (Ding *et al.* 2010). Furthermore, the paper explored the use of 3SLS regression to simultaneously estimate (1) the determinants of economic value of ecosystem services; (2) the determinants of land-use changes (i.e. the changes of forest-land cover); (3) the determinants of changes in biodiversity. The investigation was conducted first in a baseline model, where a global effect of climate change was considered, followed by regressing a modified model, in which the regional effects of climate change impacts were counted for.

To the best of our knowledge, the present paper represents one of the first attempts in the literature to formally model and test the relationship between climate change induced biodiversity loss and the consequent welfare impacts. Despite the data limitation, our preliminary results from a 3SLS regression are promising, confirmed the hypothesis that has been laid out earlier. The consistency of beta coefficients for the same variable across different ecosystem services suggests the robustness of the results.

In summary, the results of the present research suggest that a composite biodiversity indicator, integrating information about changes in species and habitats, can serve as a better option than the individual biodiversity indicators for measuring and predicting the trends of biodiversity changes in response to a set of climate and socio-economic drivers in different future climate change scenarios. For instance, in the present study, the average score of future biodiversity status (reflecting either improvement or degradation of biodiversity) is derived from the projected future trends of four different species, i.e. tree, plant, bird and herptile as well as the changes in forest habitats under different future climate scenarios, therefore the composite biodiversity indicator indicates an overall improvement or degradation of the forest ecosystems in each of the 17 EU member states in a climate change context. In this context, we are more confident to use this indicator to describe and measure the health of forest ecosystems under different climate conditions and to analyze the respective changes in its capacity of delivering ecosystem goods and services. Moreover, the structure of the composite biodiversity indicator is so simple that it can be easily used for communicating with policymakers and the broader audience.

Moreover, our results from the 3SLS regression suggest that rising temperature negatively affects biodiversity and ecosystem conditioning at an accelerating rate across geo-climatic regions in the future. In addition, we also found a strong relationship between temperature and the value of ecosystem services, but the direction of this relationship depends on the type of ecosystem services under consideration. That is to say, every 1ºC increase in temperature will contribute proportionally to the changes of the value of ecosystem services. Independent from the consideration of spatial effects of climate change, rising temperature is found positively impacting the value of provisioning and regulating services, but negatively related to the cultural services. This result is consistent with some earlier scientific findings (Garcia-Gonzalo *et al.* 2007), which state that forests in the cold geo-climatic zones, such as the Scandinavian European countries, may benefit from higher temperature in the short run due to the increased forest productivity and carbon stocks in the boreal forests. However, if we take into account the climate change induced biodiversity effects, the direct impact of rising temperature on the value of ecosystem services becomes less clear as a result of interactions between biodiversity and temperature.

In particular, the spatial effect of climate change induced biodiversity changes is captured, by introducing a cross-effect between biodiversity and temperature in the model. All in all, our results show that biodiversity and temperature can perform together as either "complimentary" or "substitute" factors to affect the supply as well as the value of certain types of ecosystem goods and services. In the case of provisioning services provided by Mediterranean forests, we find a clear "complementary" effect between biodiversity and temperature. Our results suggest that the negative impacts of climate change on biodiversity will go against the positive direct climate change impact on the Mediterranean forests, and thus generate a net negative impact on total value of provisioning services in the future. More specifically, biodiversity loss caused by increment of 1ºC in the temperature is responsible for at least 49% in every one-dollar reduction of the value of forest provisioning service in the Mediterranean forests. This finding is consistent with some of the previous studies. For instance, Linder *et al.* (2008) has found that climate change may reduces the forestry productivity in the Mediterranean region in the future, as warming will be greatest over western and southern Europe in summer, substantially affect the precipitation rate and increase the risk of extreme weather events, such as prolonged drought, storms and floods in the area. In addition, a similar positive relationship between biodiversity and ecosystem productivity in higher temperature regimes is also found in the US (Costanza *et al.* 2007). Whereas the substitute effect between biodiversity and temperature refers that climate change induced biodiversity effects on EGS may attenuate/decrease the negative direct climate change impact in some regions, where biodiversity plays a key role in mitigating the those negative impacts of climate change. For instance, this is clear for the cultural services provided by the Mediterranean forests, in which the reduction of 1ºC in the temperature is responsible for half of every 1% improvement of biodiversity indicator score. The latter will consequently contribute to nearly 28% of every additional one-dollar value generated in the cultural services provided by Mediterranean forests. Similar result is found also for the regulating services in the region, where biodiversity richness is expected to have a significant role in determining the respective values. This result may imply some important synergies of the climate and biodiversity policies. In other words, although climate change may have directly negative impacts on the value of ecosystem services, it is possible to mitigate these negative impacts by better managing biodiversity and natural resources. In many cases, the benefits derived from biodiversity can be large enough to compensate the loss of ecosystem productivities and values as a result of climate change.

However, we are also aware of the limitations in the current study. For instance, the construction of composite biodiversity indicator in this paper is subject to a significant lack of data that covers time-span long enough to describe the evolution of species from the past to the future under different climate change scenarios. As a consequence, we may observe an increase of species richness as well as forest habitats in many countries under the climate change scenarios by 2050 with respect to a baseline year of 2000, owing to the significant efforts of the EU-17 in moving towards more sustainable forest management practice. Thus, it is difficult for us to interpret, to what extent, the projected trends of changes in species richness is a result of the climate change impacts or a combination of different factors. Obviously, there is a need of incorporating more information about species richness from the far distant past into our current database, as a large time-span will enable us to rule out many other socio-economic factors other than the direct impact of climate change that affect biodiversity and ecosystem functioning. Finally, a richer historical data can also improve the overall performance of the econometric model and help us to better understand the cross-effects between biodiversity and temperature as well as the pattern in which they affect the ecosystem service values.

CHAPTER 5 THE SOCIAL DIMENSION OF BIODIVERSITY POLICY IN THE EUROPEAN UNION: VALUING BIODIVERSITY BENEFITS TO VULNERABLE GROUPS

Ding, H., Ghermandi, A. and P.A.L.D. Nunes (under preparation) 'The Social Dimension of Biodiversity Policy in the European Union: Valuing Biodiversity Benefits to Vulnerable Groups), under preparation for submission to *Journal of Environmental Science & Policy*

Abstract

This paper explores the use of spatial mapping tools, including Geographic Information Systems (GIS) to explore the social dimension of biodiversity policy, so as to identify and analyze the strength of the linkage between biodiversity and human livelihoods in different geographic locations. Our analysis is focused on Europe, where biodiversity and ecosystem benefits have been well studied for many ecosystems and will concentrate in particular on forest, coastal and wetland ecosystems both at country level and downscaled to a higher geographical resolution. In particular, we focus on European rural areas with a high density of agricultural land-use and investigate the dependencies between the socio-economic, biodiversity and ecosystem value indicators in the selected rural regions across different income groups. Moreover, social vulnerability indicators are also identified and mapped in a spatial gradient so as to investigate the role of biodiversity in the definition of social vulnerability contours maps in particular for rural communities living in remote regions. The results of this study provides important insights for EU policymakers to design potential policy instruments that can on the one hand promote biodiversity conservation and prevent natural resources from degradation, and on the other hand contribute to social stability and human livelihoods.

Keywords: biodiversity policy, biodiversity benefit, vulnerable groups, European Union, spatial analysis

JEL: Q56, Q57, Q58

Note: This paper has been submitted to the 2011 EAERE conference in Roma, Italy

5.1 Introduction

Biodiversity is a complex and multi-dimensional concept, which is generally understood as the quantity and variability among living organisms - within either species (genetic diversity), between species, or between ecosystems, underpinning the supply of a variety of ecosystem services from which humans can benefit directly or indirectly. Despite the contribution of biodiversity to human livelihoods is complex in nature, a recent study has been promoted by the United Nations' Millennium Ecosystem Assessment (MA) to investigate the complex relationship between ecosystem services and human wellbeing. As shown in Figure 1, the implications of biodiversity to the support of human livelihoods, including those of vulnerable groups such as the rural poor, can be examined by the intensity of the linkage between ecosystems, and services provided (also known as biodiversity benefits), and the constituents of human wellbeing. This includes the examination of ecosystem services such as the provision of food and water, disease management, climate regulation, flood control, spiritual fulfillment, and aesthetic enjoyment, which have been recognized as having an essential role in achieving the United Nation's Millennium Development Goals (UNEP-WCMC, 2007).

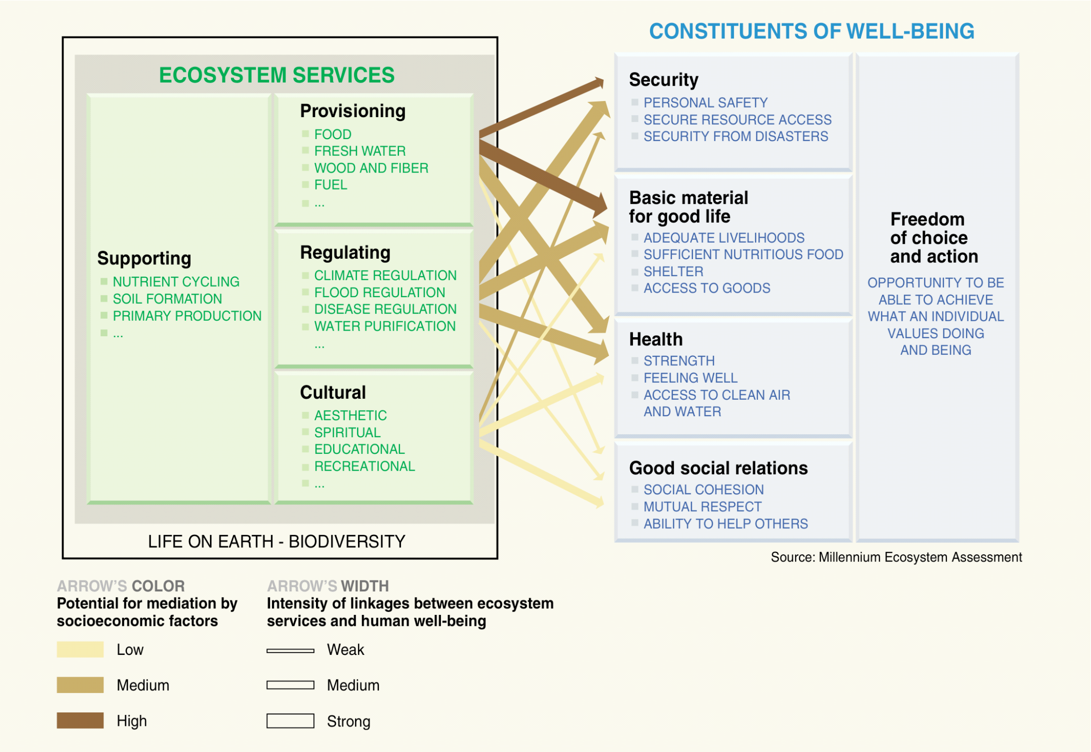

Figure 1. Linkages between ecosystem services and human well-being (Source: MEA, 2005, pp. iv)

Ecosystem services are important to different economic sectors. Primary sector activities such as agriculture, forestry, fisheries and hunting depend on a wide range of provisioning, regulating and supporting services which together shape the natural capital on which these sectors depend and determine sector inputs, processes and outputs. A variety of manufacturing activities depend on ecosystem services for the delivery of raw material inputs. Service sectors such as tourism, education and the media rely on the cultural services delivered by ecosystems. All sectors are dependent on ecosystem services indirectly in maintaining the health of the workforce, the living and working environment, and for providing protection from natural hazards.

Given that biodiversity underpins the provision of a variety of ecosystem goods and services, policies targeting at biodiversity conservation may have important implications to livelihoods enhancement and poverty alleviation. The synergies of biodiversity benefits and human livelihoods may vary in particular between developed and developing countries. For instance, a recent EC report (Nunes *et al.* 2010) has shown that in the developing world, a large proportion of employment is dependent on biodiversity and the ecosystem services it provides. By contrast, in developed regions such as the EU, the provisioning role of biodiversity and ecosystems is now responsible for only a small proportion of livelihoods. Direct employment in nature conservation is significant and growing and so is the employment in nature-based tourism and recreation (Nunes *et al.* 2010). The extent to which biodiversity conservation can benefit human livelihoods is an important question confronted by policymakers, who need to evaluate the trade-offs between biodiversity benefits and opportunity costs of conservation activities and to maximize the social benefits of biodiversity policies. The answer, however, requires an in-depth understanding of the social dimension of biodiversity policy, by analyzing the ways in which human livelihoods depend on biodiversity and ecosystem services and by examining the level of the respective dependency.

With this perspective in mind, the present paper will explore the use of spatial mapping tools, such as Geographic Information Systems (GIS) method to explore the social dimension of biodiversity policy, so as to identify and analyze the strength of the linkage between biodiversity and human livelihoods at different geographic locations. Our analysis will focus on a European scale, where biodiversity and ecosystem benefits have been well studied for many ecosystems and will concentrate in particular on forest, coastal and wetland ecosystems both at country level and downscaled to a higher geographical resolution (See Ding et al 2010, Ghermandi et al 2009a&b). Moreover, the data on socio-economic and biodiversity conditions of the countries under consideration are also well documented in the literature. These three types of information will be mapped in a spatial gradient. The results of this study are expected to provide important insights for the EU policymakers to design potential policy instruments that can on the one hand promote biodiversity conservation and prevent natural resources from degradation, and on the other hand contribute to social stability and human livelihoods (e.g. increased number of jobs in the protected area and/or ecosystem-related economic activities).

The reminder of the paper is structured as follows. In Section 2, a conceptual model is used to present the methodological framework developed for mapping and analyzing the linkages of biodiversity and human livelihoods. Section 3 defines the core socio-economic and biological indicators and introduces data to be used in the spatial analysis. Section 4 investigates the links between a country's or region's economy, its biodiversity richness and the provision of ecosystem services. Section 5 concludes the main findings and provides with policy recommendations for the EU.

5.2 Methodology

(1) A Conceptual Model for Mapping the Linkages of Biodiversity Benefits and Human Livelihoods

In the present paper, we shall embrace a conceptual model to evaluate the linkages of biodiversity benefits and human livelihoods, which shed light on two distinct value transmission mechanisms. The first captures the market value components of the biodiversity benefits on human livelihoods. A second component encapsulates the non-market dimensions – see Figure 2. Thus, human wellbeing benefits from biodiversity and ecosystem services in terms of the directly increased household revenues from resource related economic activities as well as the enhancement of various non-income benefits from the ecosystem services received.

First, with respect to income related livelihoods, ecosystem services are essential inputs for many primary sectors in the economy, including forestry, agriculture, fishery, and tourism or direct source of income/revenues to the local communities (consumers/firms) who are involved in markets trading ecosystem services, such as food and wood fuel, among others. The strength of this linkage can be estimated through a systematic economic sector analysis, and the results reflect the degree of *dependency* of the local economies with respect to biodiversity and ecosystem services, including their role in the creation of employment/income opportunities to the communities. In this context, valuing the economic revenues that rural dwellers or poor local communities can extract from the use of environmental resources enables us to assess their quantitative contribution to rural livelihoods and the extent of dependency of rural people on natural products and ecosystem services.

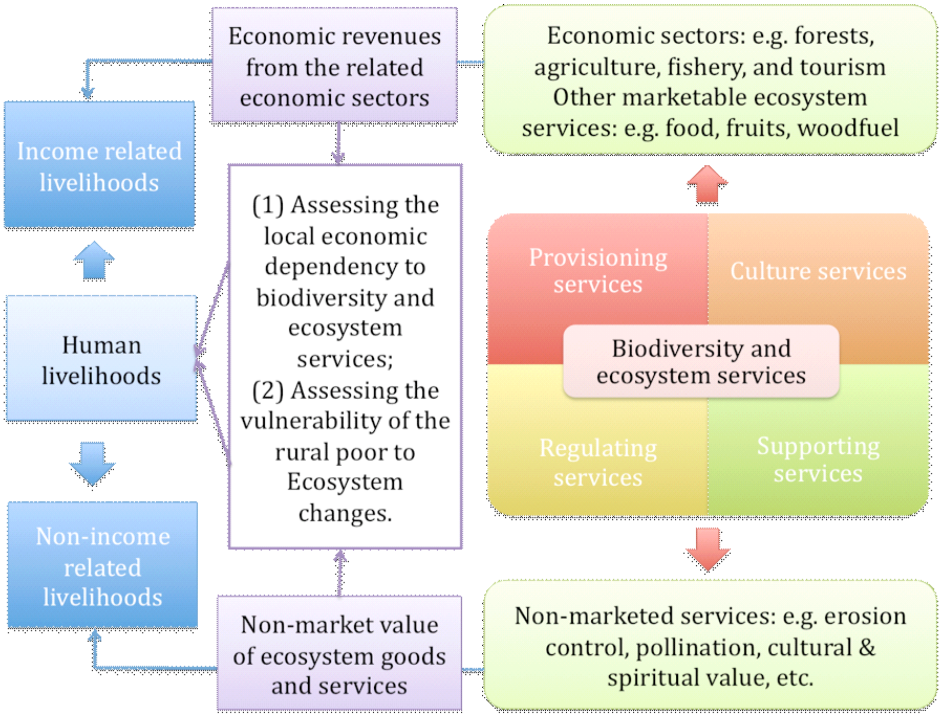

Figure 2. Framework of assessing the human livelihoods through biodiversity and ecosystem services

Second, ecosystem services also contribute to non-income related human livelihoods. The ecosystem regulating and supporting services will safeguard the living environment as well as guarantee the continuous economic activities of humans, in particular the rural dwellers; whereas the ecosystem cultural services are essential to the spiritual and cultural value of the local communities. The strength of these linkages can be estimated through a systematic economic analysis of the non-income related value of biodiversity and ecosystem services on human livelihood systems, which in turn will allow us to complement the understanding of the degree of *dependency* of the local economies with respect to biodiversity and ecosystem services. Moreover, both value transmission mechanisms will allow us to understand the degree of *vulnerability* of the local economies, in particular the rural poor, with respect to changes, or losses, of biodiversity and the respective impacts on the provision of ecosystem services.

Finally, it is important to note that the economic valuation exercise stems from microeconomic theory, proving a partial-equilibrium analysis of the economic problem at a local scale. In the case of quantifying the biodiversity benefits to the rural poor, we are particularly interested in the cash or non-cash income that local communities can obtain from the extractive use of natural resources and how much can this contribute to rural livelihoods. This perspective indicates that the current economic analysis focuses on the supply side of products, which are transformed into benefits to the economy by either being used as resource endowments in production of the primary sectors (e.g. timber production) or being provided to outsiders in the form of ecosystem-based services (e.g. recreation/tourism services). Although benefits of ecosystem services exist in different forms, it is clear that both benefits can be traced directly/indirectly in the marketplace and lead to the increase of cash income and the creation of new job opportunities to the local population. Therefore, we interpret the estimated economic values of ecosystem services as the contribution to the total income that supports the livelihoods of rural communities. The magnitude of the ecosystem value can also reflect the poverty level of vulnerable groups in the rural areas.

(2) GIS Spatial Mapping of Biodiversity Benefits and Rural Vulnerable Groups

Empirical evidence has shown spatial coincidence between ecosystem services and strong dependence of poor rural livelihoods on those services (Chomitz and Nelson, 2003; Müller et al., 2006 and Dasgupta et al., 2005). Such strong dependence on natural resources makes the rural poor very vulnerable to any changes in ecosystems and biodiversity. Natural resource degradation and biodiversity loss can affect the poor by impairing household consumption derived from natural products and the proportion of wealth generated in ecosystem-related production and employment. In this context, GIS maps can be a powerful tool for investigating the spatial coherence of biodiversity and rural vulnerable groups, identifying conservation priorities and the cost-effective biodiversity policies that promote both biodiversity conservation and poverty alleviation. In the analysis we strongly rely on Geographic Information Systems (GIS) to integrate different spatial layers of information, which are targeted at capturing various levels of socio-economic characteristics of the population, biodiversity richness or economic value of ecosystem services. In the context of GIS mapping, we focus in particular on those vulnerability-related indicators that allow us to look for in detail to the spatial disaggregation of the data. In the following sections, the role of biodiversity and ecosystem services in supporting human well-being is discussed at different geographical scales and for different types of vulnerability in poor economies, rural communities and remote communities.

Spatial mapping requires both data quality and quantity, therefore we only focus on the European countries, where best information is available at country level, for describing (1) the socio-economic characteristics, (2) the value of ecosystem goods and services, and (3) biodiversity conditions. More specifically, we will explore the use of a set of indicators to evaluate and map all three abovementioned aspects in a spatial gradient, so that we are able to identify and analyze the strength of the linkage between biodiversity and human livelihoods at different geographic locations – see Figure 3. Finally, the outcome of the spatial analysis have important policy implications in terms of identifying locations of policy priorities where policy instruments can be most cost-effective and of reallocating resources between winners and losers so as to improve the efficiency of biodiversity policy. If empirical evidence supports the assumption that a biodiversity rich area is associated with high poverty, then the enforcement of well-defined biodiversity policies are expected to have multiple positive effects in these regions, in terms of reducing natural degradation, improving the living environment of the rural poor, and increasing income and employment opportunities to the local communities. In principle, the outcomes of such policy implementation will be reaching the social optimum.

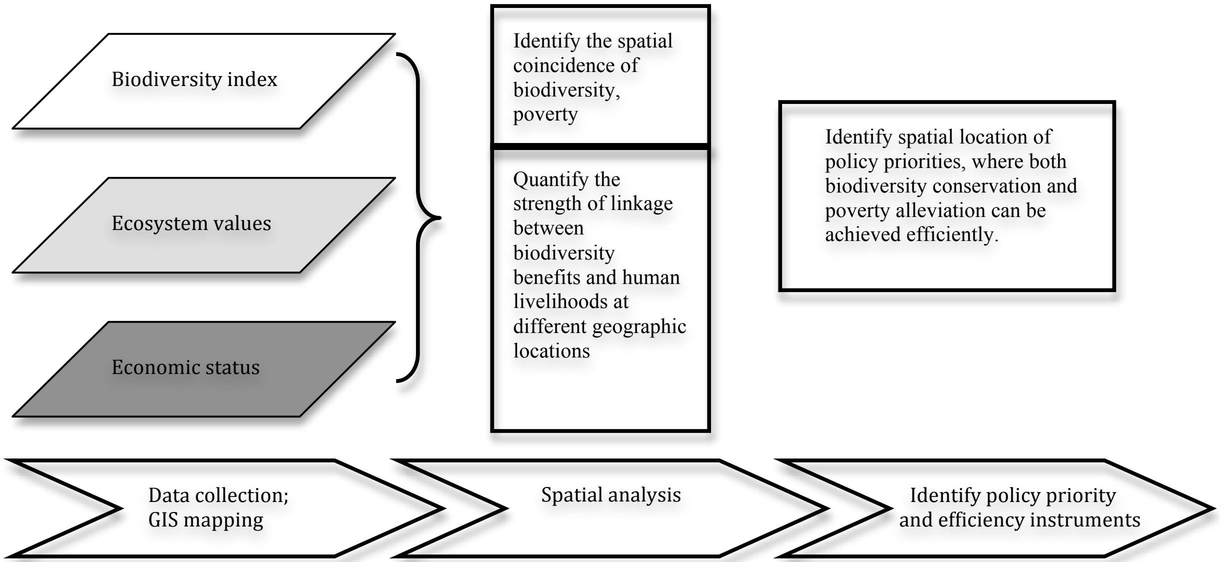

Figure 3. An illustration of the GIS analysis of spatial coincidence of biodiversity richness and human livelihoods

5.3 Data

(1) Identification of the Rural Poor in Europe Using Socio-Economic Indicators

Poverty is multidimensional and encompasses inability to satisfy basic needs, lack of control over resources, lack of education and skills, poor health, malnutrition, lack of shelter, poor access to water and sanitation, vulnerability to shocks, violence and crime, lack of freedom and powerlessness. In most world areas, the poorest people of a country are often the indigenous people or ethnic minorities who live in a remote location or on the marginal lands of rural areas, relatively far from essential elements of the modern economies, such as big cities, large paved roads and ports. Whereas in Europe, rural poverty is practically nonexistent in the European Union (EU) and in Northern Europe, where 25-40% of total population is rural. However, poverty in Europe is on the rise due to the extension of new member states in Central and Eastern Europe. For instance, in Romania and Bulgaria, almost 40 per cent of the poor people are the Roma community, who are among the poorest people in Europe. More than eight out of ten in the Republic of Moldova live below the two-dollar-a-day poverty line, many of them in rural areas[25].

In many rural areas of the new member states, poverty has increased as a result of privatization of former collective and state farms after the collapse of the former communist system, leaving rural workers unemployed and with few opportunities for alternative employment. In particular, lack of local employment, distances from the markets of Western Europe, and scarcity of land and plot fragmentation are key factors that determine the rural poverty in the region and result in a flow of rural migration to urban areas in search of jobs and services (IFAD, 2002). Poverty is becoming an important issue in Europe as it comes hand in hand with vulnerability, a measurement of the societal resistance or resilience of rural communities to the loss of biodiversity and ecosystem services, reflecting their inability of adapting to any shocks and damages (e.g. climate change, floods and drought) to the natural resources on which their livelihoods depend. High vulnerability arises in the poor rural communities whose livelihoods are directly extracted from the sale of primary resources (farmers, fishermen and foresters) or reliant on the selling of their labour. Moreover, vulnerability may also increase with respect to the increasing remoteness of communities whose potential is limited in terms of their accessibility to markets in big towns/cities, and additional source of income from off-farm employment opportunities in the nearby urban areas. In response, the EU has earmarked a significant part of its common budget for development of the least advantaged rural areas within new member states in Eastern Europe.

To profile the rural poor in the European countries under consideration, four key socio-economic indicators, including GDP per capita (2007US$, PPP), agriculture added value over GDP, unemployment rate (% of population aged 15 and over, 2007) and rural population (% of total, 2007) are chosen to measure the level of economic development in each country and the

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[25] http://www.ruralpovertyportal.org/web/guest/region/home/tags/europe

importance of primary sectors in the country's economy. Table 1 summarises the information of key socio-economic indicators across different income groups.

Table 1. Socio-economic vulnerability indicators in European countries

		Socio-economic Indicators			
OECD Income groups	Country	GDP per capita (2007US$, PPP)	Agriculture added value over GDP	Unemployment rate, 2007 (% of population aged 15 and over)	Rural population, 2007 (% of total)
High income	Austria	44,879	2%	4.4	33
	Belgium	42,609	1%	7.5	3
	Denmark	57,051	1%	3.8	14
	Finland	46,261	3%	6.9	37
	France	41,970	2%	8.3	23
	Germany	40,324	1%	8.6	26
	Ireland	59,324	2%	4.6	39
	Luxembourg	103,042	0%	4.1	17
	Netherlands	46,750	2%	3.2	19
	Norway	82,480	2%	2.5	23
	Sweden	49,662	1%	6.2	16
	Switzerland	56,207	1%	3.7	27
	UK	45,442	1%	5.3	10
Middle income	Czech	16,934	3%	5.3	26
	Greece	27,995	4%	8.3	39
	Italy	35,396	2%	6.1	32
	Portugal	20,998	3%	8	41
	Spain	32,017	3%	8.3	23
	Slovenia	23,379	3%	4.8	51
Low income	Hungary	13,766	4%	7.4	33
	Poland	11,072	5%	9.6	39
	Slovakia	13,891	4%	11.1	44
	Bulgaria	5,163	9%	6.9	29
	Croatia	11,559	7%	9.6	43
	Estonia	15,578	5%	4.7	31
	Latvia	11,930	4%	6	32
	Lithuania	11,356	5%	4.3	33
	Romania	7,703	10%	6.4	46

Source: World Bank - World development indicator; UNDP - Human Development Indicator; EUROSTAT

EU countries are not homogeneous with respect to the average income levels. For instance, the GDP per capita in the European countries considered in this study ranged in 2007 between \$82,480–\$103,042 in, respectively, Norway and Luxembourg, and \$5,163–\$7,703 in Bulgaria and Romania. Such disparities are captured in the OECD classification of economies, which identifies three distinct groups: high-income, middle-income and low-income[26]. Non-OECD countries are classified in Table 1 based on the relative value of GDP per capita in 2007 as middle-income economies (Slovenia) or low-income economies (i.e., Bulgaria, Croatia, Estonia, Latvia, Lithuania, and Romania). The unemployment rate provides some insights on a country's social stability and the size of rural population is an important demographic indicator for calculating population density and income disparities between the rural and urban areas. Moreover, the table also shows that an average of nearly 40% of the population in the selected Eastern and Southern European countries are rural, with agriculture added value over GDP doubled compared to those of the industrialized northern and western zones of Europe.

Agriculture added value over GDP is an important socio-economic indicator for measuring the extent to which a nation's economy can depend on its primary products - raw materials extracted from land and ocean. It refers to the net outputs of primary sectors - including forestry, hunting, and fishing, as well as cultivation of crops and livestock production - after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources. Apparently, this indicator embraces all kinds of agricultural products that are traded in the marketplace. The economic dependence of less developed economies on natural capital is considered more significant than those in the developed countries because the economic structure of the former is based on the production and export of primary products, which are characterised by high labor intensity production, but low technical inputs. Thus in Table 1, a high value of this indicator is found to correspond to poorer economies in the low-income category, while low value of the same indicator falls between high- and middle- income categories. In other words, high agriculture added value over GDP indicates that the country's economy depends largely on the quantitative extraction of natural resources. Thus, this indicator can be used to indicate which communities may appear more vulnerable to changes in biodiversity and ecosystem services.

(2) Spatial Profile of the Biodiversity in Europe

In order to characterize the spatial distribution of biodiversity in Europe, we rely on the index of biodiversity described in Wendland et al. (2009). Such index builds upon the information on species ranges of mammals, birds and amphibians from global vector data (Baillie et al., 2004;

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[26] The OECD classification distinguishes three income categories as follows: i.e. high-income countries (with a GDP per capita about $29,254 USD), middle-income countries (with a GDP per capita between $19,244 USD and $29,254 USD) and low-income countries (with a GDP per capita lower than $19,244 USD) (OECD, 2010).

BirdLife International, 2006; IUCN, 2006) and combines it in a single index by weighing species ranges by their threat status as defined by IUCN's Red List (IUCN website, 2007). The technical details on the weighing procedure and construction of the aggregated index are given in Wendland et al. (2009). The final index is presented in a 30 arc second grid (approximately 1 km at the equator) and is mapped globally. In Figure 4, we present the distribution of the biodiversity index within Europe.

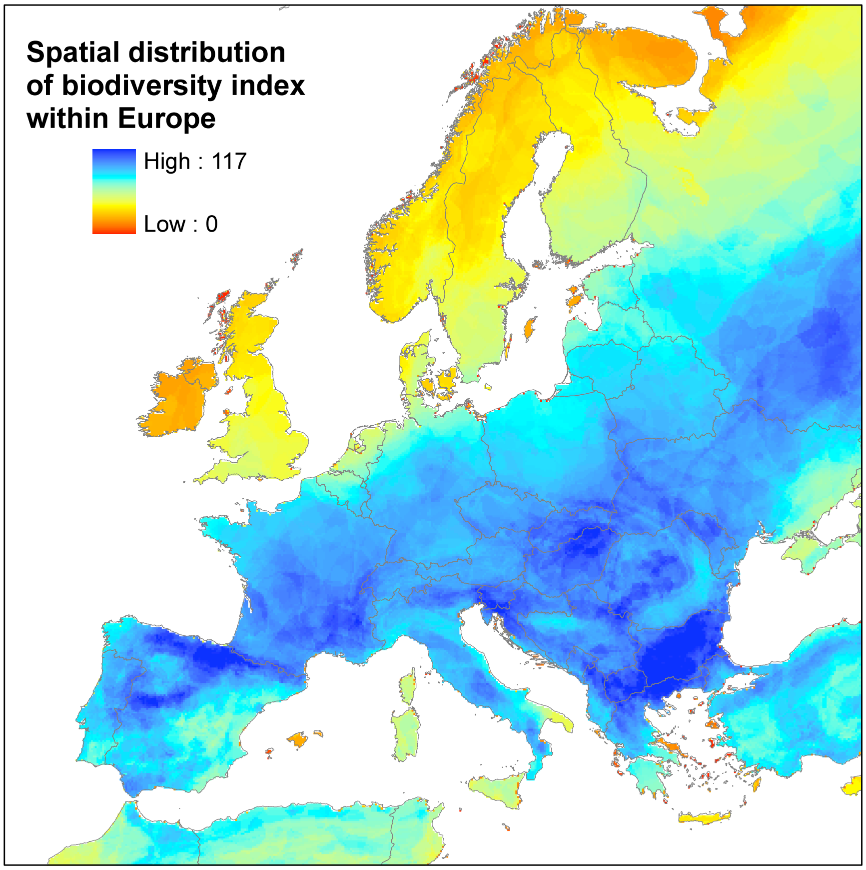


Figure 4. Distribution of terrestrial biodiversity within Europe (based on Wendland et al., 2009)

Figure 4 shows that terrestrial biodiversity is distributed unevenly in Europe. North European countries including Scandinavia, United Kingdom, and Ireland are characterized by relatively low biodiversity. The highest values of terrestrial biodiversity within Europe are found in East European countries, notably Bulgaria and Slovakia, and in the Northern regions of Spain. Within some countries there is an important range of variability in the index. For instance, in Italy high values of the biodiversity index are to be found in mountainous regions in the Alps and Apennines, while low-lying regions and, particularly, islands present lower values of the index. It is important to notice that, at a global scale, European countries score rather poorly in the biodiversity index compared to biodiversity hotspots in South America, Africa and South East Asia where the highest values of the index are found (up to 407).

Table 2. Biodiversity indicators for Europe

Country	Bird species (number)[1]	Mammal species (number)[1]	Reptile species (number)[1]	Vascular plant species (number)[1]	Biodiversity index[2]
Albania	303	73	37	3031	76.29
Austria	412	101	16	3100	76.52
Belgium	427	92	12	1550	62.13
Bulgaria	379	106	33	3572	91.31
Bosnia-Herzegovina	312	78	27	-	77.69
Switzerland	382	93	17	3030	77.35
Czech Republic	386	88	11	1900	76.60
Germany	487	126	15	2682	68.99
Denmark	427	81	8	1450	36.50
Spain	515	132	67	5050	70.81
Estonia	267	67	6	1630	54.85
Finland	421	80	5	1102	39.70
France	517	148	46	4630	76.46
United Kingdom	557	103	16	1623	34.73
Greece	412	118	63	4992	62.74
Croatia	365	96	34	4288	76.90
Hungary	367	88	18	2214	84.62
Ireland	408	63	6	950	22.93
Italy	478	132	55	5599	67.14
Lithuania	227	71	6	1796	67.32
Luxembourg	284	66	9	1246	71.94
Latvia	325	68	7	1153	60.33
Macedonia	291	89	29	3500	89.93
Netherlands	444	95	13	1221	49.16
Norway	442	83	7	1715	29.65
Poland	424	110	11	2450	70.82
Portugal	501	105	38	5050	68.75
Romania	365	101	22	3400	78.36
Serbia and Montenegro	381	96	35	4082	81.01
Slovakia	332	87	14	3124	83.67
Slovenia	350	87	29	3200	85.71
Sweden	457	85	7	1750	34.14

[1] Source: UNEP-WCMC (2004)

[2] Estimated by the authors based on the index in Wendland et al. (2009)

Table 2 below summarizes the information on various biodiversity indicators assessed at country level. The data on the number of known bird, mammal, reptile, and vascular plant species were gathered from UNEP-WCMC (UNEP, 2004) and are compared to the average score of the biodiversity index by Wendland et al. (2009) for each European country. Overall, the highest biodiversity in terms of number of species of birds, mammals, amphibians, and vascular plants is found in France, Italy, and Spain. All three countries are characterized by a relatively high value in the biodiversity index. It is reminded that the index is not constructed only based on the number of species but also on their threat status as defined by IUCN's Red List. Despite the smaller range of species, several Central and East European countries (e.g., Bulgaria, Macedonia, Slovenia) are characterized by a higher score in the biodiversity index. On the lower side of the range, countries such as Estonia, Ireland, Lithuania, Luxembourg and Latvia present the smallest range of animal and plant species. Ireland also has the lowest values among the considered countries for what concerns the biodiversity index. Notably, the United Kingdom is characterized by the largest number of known bird species but shows a relatively low diversity in reptiles and vascular plants and is characterized by a low value of the biodiversity index.

(3) Profile of Ecosystem Values in Europe

This section reports economic values provided by a number of key ecosystems in Europe, including forest ecosystems, marine/costal ecosystems and freshwater/wetland ecosystems. The three ecosystems are valued in terms of three types of ecosystem service defined in the MEA report (2005), including provisioning services, regulating services and cultural services. The valuation exercise is conducted based on a hybrid economic valuation methodology (Ding et al. 2010), which combines the use of alternative valuation techniques, depending on the type of ecosystem under consideration. In this study, data are taken from various sources. Bio-physical data regarding the land-use changes and quantity of various forest products and carbon stocks are taken from FAO (2005). Economic valuation databases (such as EVRI) are surveyed to select original non-market valuation studies for meta-analysis and value transfer. The final numeric valuation results are derived from a partial analysis, which considers only a subset of all ecosystem types and services. The total value of forest ecosystem embraces provisioning, regulating and cultural services (Ding et al. 2010). As for wetlands and freshwater ecosystems, marine/ coastal ecosystems, valuation results are the results of two meta-analyses. While the values of wetlands and freshwater reflect the total economic value of these ecosystems, the value of coastal areas is limited to their recreational value (Ghermandi et al. 2010a,b). Finally, in order to illustrate the contribution of ecosystem benefits to the local economies, we calculated the percentage of total value provided by each ecosystem type over a country’s GDP.

The valuation results for the selected ecosystems are used in this study as an indicative measure of the magnitude of the contribution of the considered ecosystem services to the wellbeing of the populations of beneficiaries, whether at the local level or at the country level. In this context, the valuation exercise will shed light on the quantitative assessment of the impacts of losing biodiversity and ecosystem services on the beneficiaries, including vulnerable groups such as the rural poor. In addition, economic valuation will also constitute one instrument on which to design and evaluate biodiversity policy instruments aimed at improving the current allocation of market driven resources, enhancing the environmental sustainability of economic activities as well as contributing to alleviating poverty, enhancing social structure and creating jobs. Therefore, valuing ecosystem services, understanding their contributions to human livelihoods and identifying the beneficiaries and relevant stakeholders is important for any policy design targeted at (1) halting biodiversity degradation, (2) correcting the externalities, (3) compensating the losers of biodiversity loss, (4) creating incentives to more effective conservation of biodiversity, and (5) ultimately sustaining the long-term local economic development and human well-being,

The estimated economic values of three ecosystems are summarized in Figure 5, which shows how the total values of ecosystem services—calculated as percentage of GDP—and their composition in terms of the considered ecosystem types vary across different countries and income categories. As one can see, among high-income countries, Finland, Sweden and Ireland show the highest value of ecosystem services with respect to the national GDP. This is partly due to the large total area of wetland and freshwater ecosystems in these countries, which, despite the low per-hectare values (see Table A10- in Appendix) results in high aggregated values. Secondly, the value of forest provisioning services in Sweden and Finland are particularly high, reflecting the fact that forestry is a widely practiced activity in these countries (see Table A11 in Appendix). In middle-income countries, relatively high values of forest ecosystems are found in countries that are landlocked or with a short coastline, such as the Czech Republic and Slovenia, while in the remaining countries high values are provided by wetlands and freshwater ecosystems and coastal recreation. In low-income countries, ecosystem service values tend to be high particularly for forests and, in Bulgaria and Croatia, wetlands and freshwater ecosystems. The high value of wetlands and freshwater ecosystems in Bulgaria and Croatia reflects the relatively high per-hectare values and the low GDP in those countries.

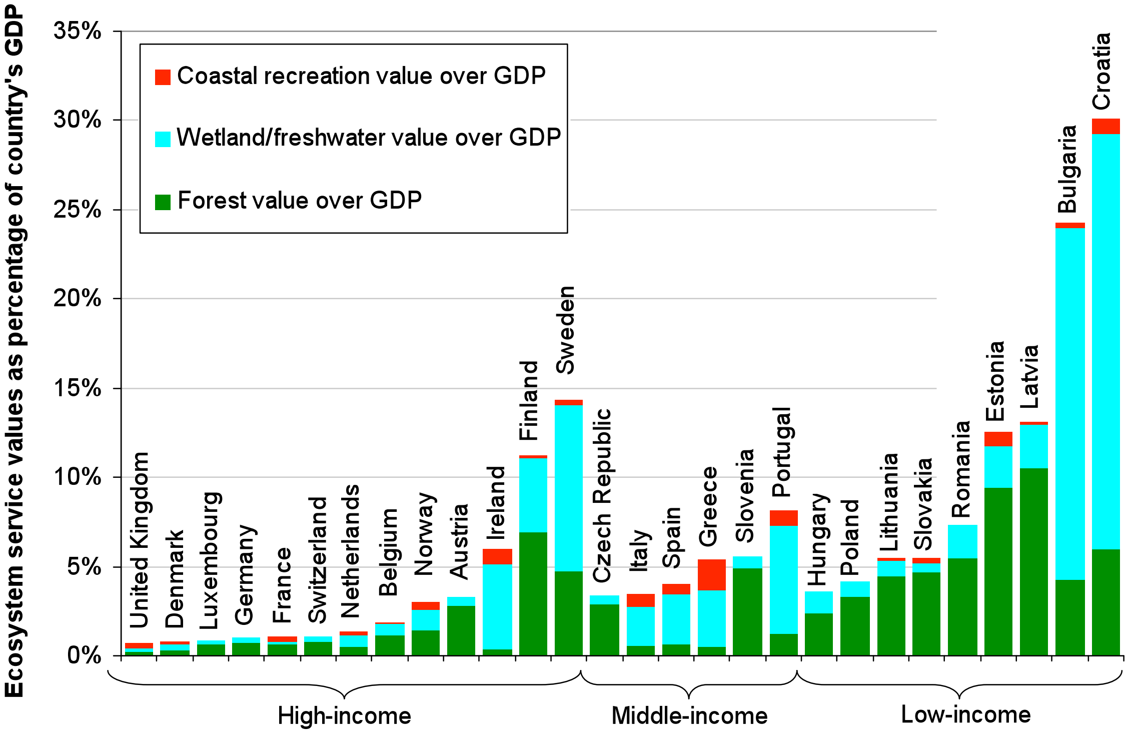


Figure 5. Contribution of forests, wetlands, freshwater and coastal ecosystem service values as percentage of country's GDP

5.4 Spatial Analysis of the Dependency of Human Livelihoods on Benefits of Biodiversity and Ecosystem Services in Europe

As previously discussed, environmental income can play a crucial role in the livelihoods of communities in rural and remote locations, especially the poorest. Moreover and despite the fact that biodiversity and environmental conservation policies are mostly advocated in developed economies, larger proportions of the more pristine and less exploited natural resources are found in less developed economies where the resources are and were in the past less extensively exploited to support economic activities.

The purpose of this section is to investigate the links between a country's or region's economy, its biodiversity richness and the provision of ecosystem services. The information on socio-economic indicators and the spatial profile of biodiversity in European countries is combined here with the results of the economic valuation of the ecosystem services provided by European ecosystems discussed in Section 3. The goal is to identify possible patterns in the level of dependency of national and local economies on the benefits of biodiversity and ecosystem services across a range of indicators, which are chosen to represent different degrees of economic development and vulnerability. Otherwise stated, the objective of the investigation is to test whether poor and vulnerable rural and remote communities are more strongly dependent on the provision of ecosystem services.

(1) Income-Related Vulnerability and the Link to Biodiversity

Household income level can be interpreted as a measure of the risk to fall into poverty or deeper poverty in the future as can be triggered by shocks at the community level or at the national and international level. It can thus provide an indication of the vulnerability of communities to socio-economic or environmental changes at the local or larger scale.

The countries in the European Union are not homogeneous with respect to the average income levels. In Figure 6 the average values of the selected socio-economic, biodiversity and ecosystem service value indicators across the three OECD income categories are presented. The socio-economic indicators chosen are the rural population as percentage of the total population, the unemployment rate in 2007 and the added value of agriculture to the country's GDP in 2007. The ecosystem services indicator reflects the total economic value of forests, wetlands, freshwater ecosystems and recreation in coastal areas as elicited in Section 3 over the total GDP of the country. The biodiversity indicator is the country average of the terrestrial biodiversity indicator discussed in Section 3.

The results in Figure 6 highlight the presence of a correlation between ecosystem services, biodiversity and income-related vulnerability in the selected European countries. Moving from high-income to low-income countries one can note that the values of all socio-economic indicators increase towards higher vulnerability. The unemployment rate increases from 5.3% to 7.3%, the percentage of rural population from 22% to 37% and the dependence of GDP from the agricultural sector increases from 1.5% in high-income countries to 5.9% in low-income countries. High income countries show, however, a lower value of the biodiversity index than low-income countries. The dependence of the latter economies from ecosystem services is, on the other hand, higher. Ecosystem service values account for 11.8% of the GDP of low-income countries while only for 3.6% of high-income economies.

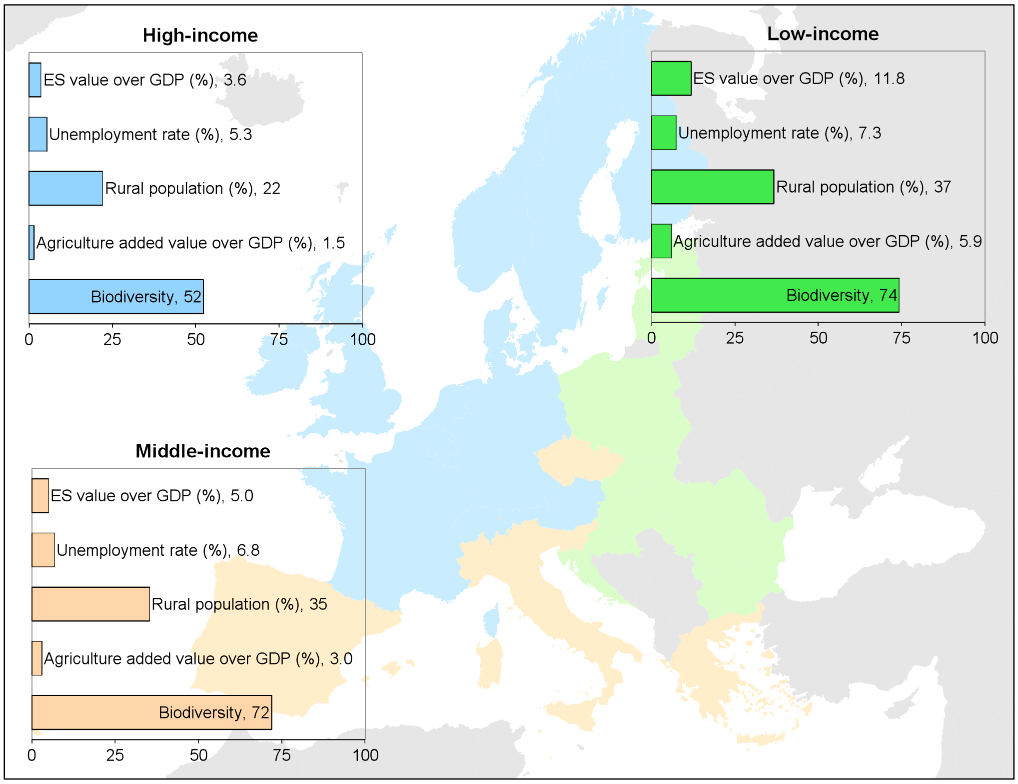
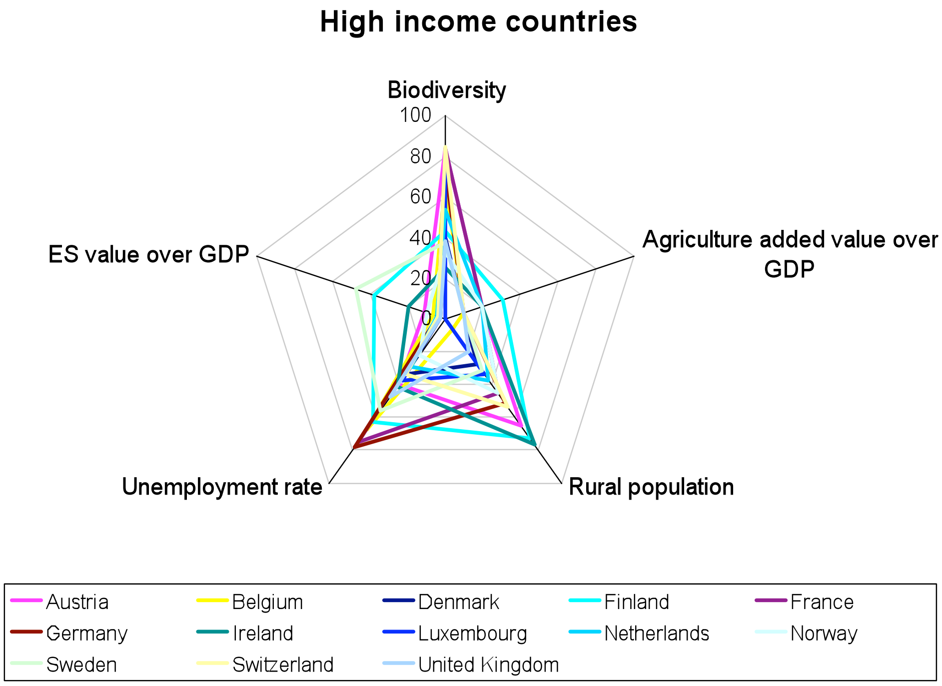


Figure 6. Average value of socio-economic, biodiversity and ecosystem service indicators in European countries according to income categories

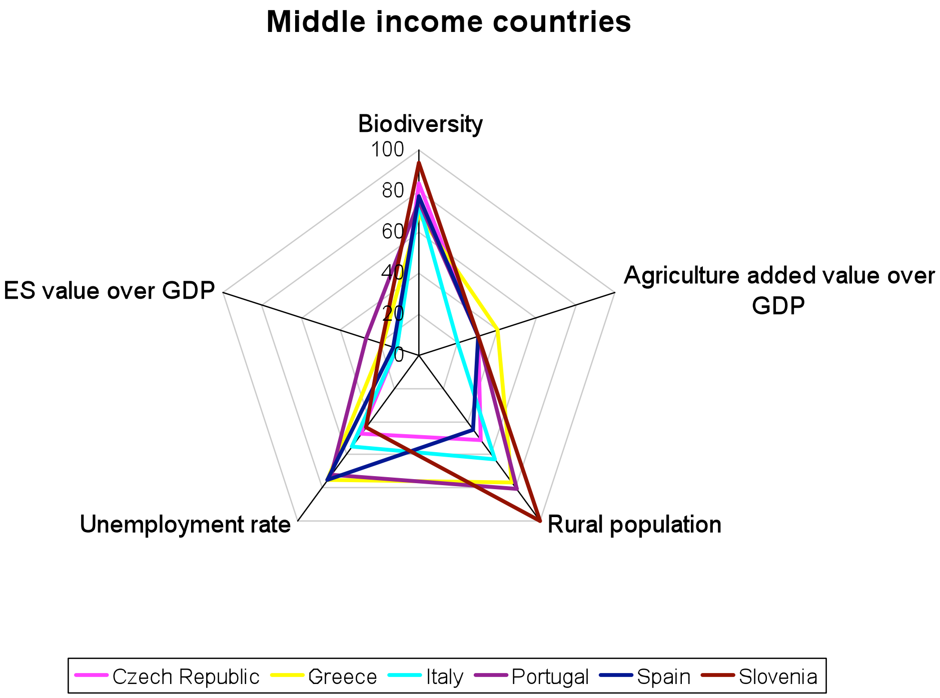
The dependencies between the three dimensions in the individual countries emerge more clearly in Figures 7(a)-(c) where European countries are grouped according to their income level based on the OECD classification and each of the axes in the spider charts represents one of the indicators. To enhance the readability of the results, the values of the indicators were standardized between 0 and 100, so that for each indicator the highest value on the axis is attributed to the country with the highest value of the indicator and the values for the remaining countries are rescaled accordingly.

Figures 7 (a)-(c) identify the possibility contours of human livelihoods, biodiversity and ecosystem services in European countries. Among the three income categories, the narrowest boundaries are found in high-income countries. With the exception of Austria, France and Switzerland, the biodiversity levels are lower than the average values in middle- and low-income countries. Moreover, the contribution of agricultural activities to the countries' economy is generally low, with the exception of Finland, where agriculture added value accounts for 3% of the GDP and 37% of the population lives in rural areas. Ecosystem service values generally provide a small contribution to the economy of high-income countries, with the notable exception of Sweden and Finland where they account for 14% and 11% of the country's GDP. In middle-income countries one can notice an enlargement of the boundaries, with the added value of agriculture, rural population and biodiversity levels increasing compared to high-income countries.

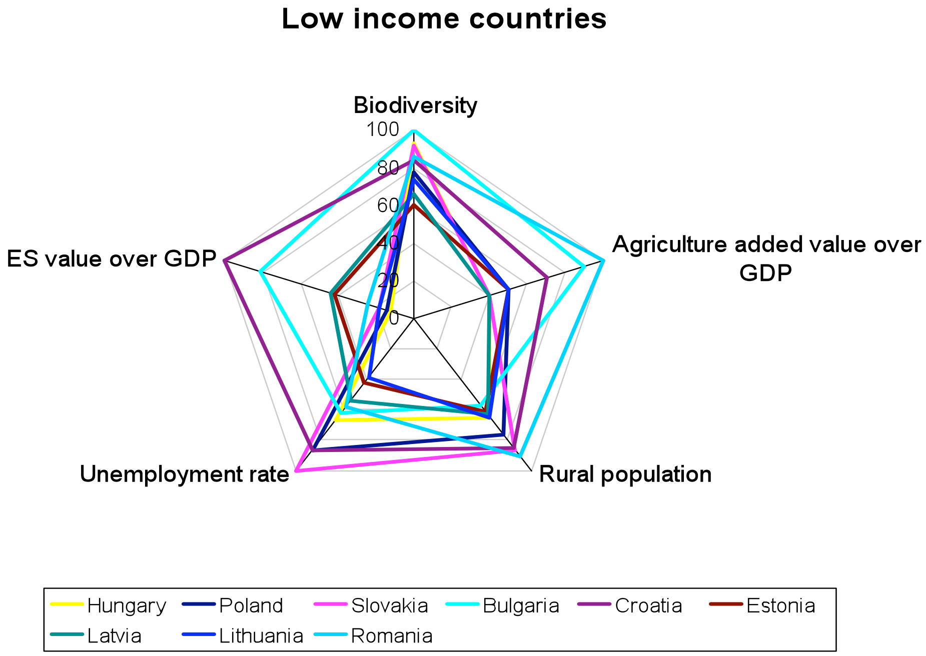
The largest possibility contours are found however in low-income countries where the highest levels of agricultural added value (10% in Romania), unemployment rate (11.1% in Slovakia) are found, suggesting a higher vulnerability of these economies to socio-economic and environmental shocks. Significantly, the highest values of biodiversity (91.3 in Bulgaria) and ecosystem service value over GDP (30% in Croatia) are also found in low-income economies. This suggests a large potential for biodiversity, mediated through the provision of ecosystem goods and services, to act as a positive stimulus for the countries' economy, create employment, and contribute to the livelihood and welfare of the populations.



(a)



(b)



(c)

Figure 7. Linkage between ecosystem services value, biodiversity and socio-economic indicators in (a) high-income European countries; (b) middle-income European countries; (c) low-income European countries

(2) Vulnerable Rural Communities and Their Dependency on Biodiversity

Because they are more highly dependent on the natural environment for the provision of food, shelter, and income, rural poor communities are more vulnerable to environmental and socio-economic changes. Biodiversity loss and degradation in the provision of ecosystem services may further aggravate the risk of social exclusion for such communities. Rural agricultural households are particularly vulnerable, since their income may be expected to be more subject to variability than, for instance, low-income workers in urban areas. For this reason we focus in this section on rural agricultural areas to investigate the link between the livelihood of the rural poor, biodiversity and the provision of ecosystem services.

Among all NUTS2 regions in Europe, those with the highest density of agricultural land-use were selected, based on the land-use patterns identified by the Corine land use map. For the calculation, all the grid cells identified as "agricultural areas" in Corine were considered. These include arable land (i.e., non-irrigated, permanently irrigated and rice fields), permanent crops (i.e., vineyards, olive groves, fruit trees and berry plantations), pastures, and heterogeneous agricultural areas (i.e., annual crops associated with permanent crops, complex cultivation patterns, land principally occupied by agriculture with significant areas of natural vegetation, and agro-forestry areas). Among regions with agricultural land-use density of 70% or higher, the three NUTS2 regions with the lowest and highest GDP per capita in 2007 – based on GDP per capita data referring to year 2007 from Eurostat – were selected in order to verify the existence of different patterns in their dependence from biodiversity and ecosystem services. The three rural poor regions identified with this procedure are: Del-Alfold and Eszak-Alfold in Hungary, and Lubelskie in Poland. In addition, and for the sake of a running a comparative analysis, the three rural regions with highest GDP per capita values among the regions with a strong agricultural land-use density are also selected. We refer to Southern and Eastern Ireland, Berkshire, Buckinghamshire and Oxfordshire in the United Kingdom, and Groningen in the Netherlands. Table 3 summarizes the characteristics of the selected NUTS2 regions, including the values of the socio-economic, ecosystem service value and biodiversity indicators.

The total value of ecosystem services in the selected NUTS2 regions was calculated multiplying the average per-hectare value in the country where the regions are located (as calculated in Section 3) by the total area of respectively forests, wetlands and freshwater ecosystems. Coastal recreation was not considered in this analysis since some of the regions are landlocked (Del-

Alfold, Eszak-Alfold, Lubelskie, and Berkshire, Buckinghamshire and Oxfordshire) while the remaining are not. The total area of forests and wetlands/freshwater ecosystems in each NUTS2 region was estimated based on the land-use categories of Corine and with the procedure previously described in Section 3. The value of the terrestrial biodiversity index in table 3 is the average value in each of the considered NUTS2 regions.

Table 3. Indicators of socio-economic condition, biodiversity richness and ecosystem services value in selected rural agricultural NUTS2 regions of Europe

NUTS2 region	GDP per capita, 2005 (US$/person /year)	Employment in primary sector, 2006 (% of total employment)	Unemployment rate, 2007 (% of population aged 15 and over)	Biodiversity index	Forest ecosystem service value (% of GDP)	Wetlands/ freshwater ecosystem service value (% of GDP)
Southern and Eastern (IE)	45,321	4.70	4.5	23.0	0.2	2.7
Berkshire, Buckinghamshire and Oxfordshire (UK)	43,269	1.19	4.0	40.4	0.1	0.0
Groningen (NL)	43,998	3.17	4.9	45.3	0.2	0.8
Lubelskie (PL)	9,773	35.86	9.5	77.1	4.2	0.8
Eszak-Alfold (HU)	10,708	4.42	10.3	87.6	1.5	1.8
Del-Alfold (HU)	11,388	9.38	10.8	82.8	1.7	1.9

The dependencies between the socio-economic, biodiversity and ecosystem value indicators in the selected rural regions are graphically visualized in Figure 8. Each of the axes in the spider chart represents one of the indicators, with the values of the indicators standardized between 0 and 100.

Figure 8 shows that the contours of human livelihood, biodiversity and ecosystem service values differ substantially between the two groups of regions, despite the fact that both groups represent rural agricultural areas. In low-income regions, both the employment in the primary sector as a share of total employment and the overall unemployment rate are higher, suggesting that these areas are particularly vulnerable to socio-economic changes and environmental degradation. The low employment rate in high-income agricultural regions may be explained by the high level of mechanization of agricultural practices in these areas. On the other hand, biodiversity levels are substantially higher in low-income regions and the value of forest ecosystem services is particularly high when compared to the total GDP of these regions. This supports the hypothesis that the economic structure of vulnerable rural regions of Europe – such as the selected low-income, agricultural regions – is more strongly dependent on biodiversity and the provision of ecosystem services than that of richer areas, even if remote and predominantly agricultural.

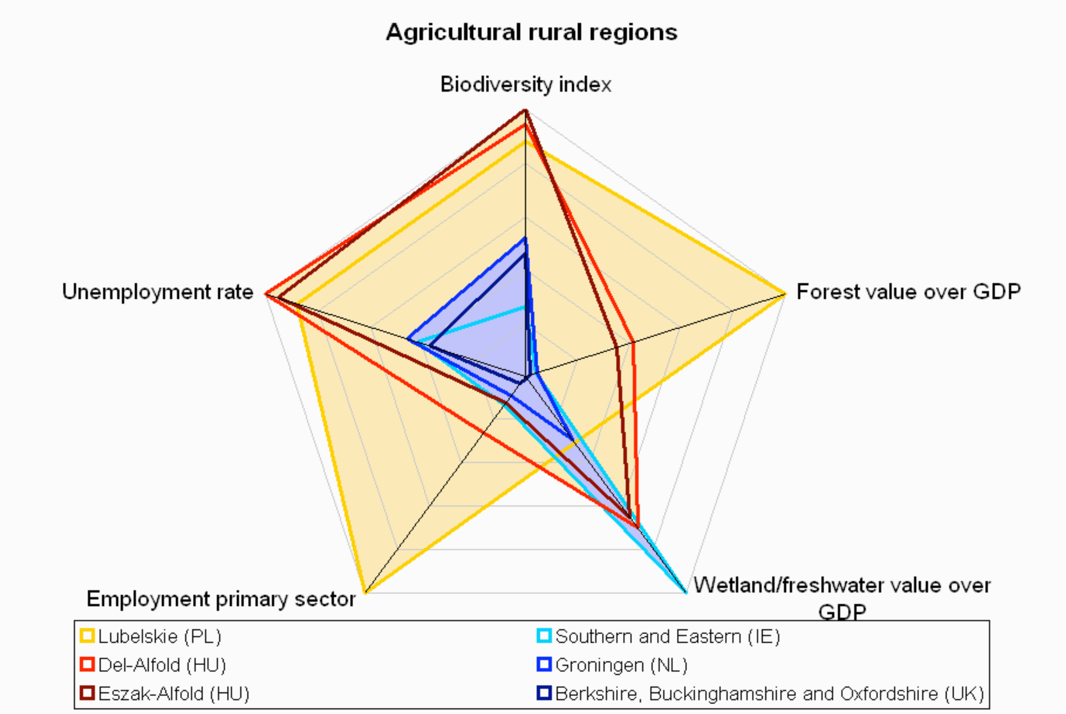


Figure 8. Linkage between ecosystem services value, biodiversity and socio-economic indicators in selected rural agricultural regions of Europe

(3) Vulnerable Remote Communities and Their Dependency on Biodiversity

Communities living in remote regions are more vulnerable than populations in more accessible regions since access to substitute products and services may not be available or expensive. In mountainous areas, for instance, income alternatives are often scarce and communities are in general strongly dependent on the natural environment for their wellbeing. Here, we focus on two types of remoteness: first we consider mountainous regions of Europe as case-study for geographical remoteness, and second we look at distance from major cities as an indicator of the social dimension of accessibility.

The procedure followed for the selection of the mountainous case-study regions reflects the method used for the discussion of rural agricultural regions. Among all NUTS2 regions in Europe, we selected the regions with average elevation equal or higher than 700 m a.s.l. The average elevation in each region was obtained in a GIS software, based on the information contained in the NOAA Digital Elevation Model, with 5 minutes resolution (http://www.ngdc.noaa.gov/mgg/global/seltopo.html). Among such regions, the three with the lowest GDP per capita and the four with the highest GDP per capita were selected for further investigation. The three remote poor regions are Yugozapaden in Bulgaria, Centru in Romania, and Ipeiros in Greece. The regions with highest GDP per capita are the Austrian regions of Salzburg, Vorarlberg, and Tirol and the Provincia Autonoma Bolzano/Bozen in Italy. The latter was included in the analysis as a fourth region in order to provide a differentiation of the considered regions across at least two different countries (i.e., Austria and Italy). Table 3 summarizes the characteristics of the selected NUTS2 regions, including the values of the socio-economic, ecosystem service value and biodiversity indicators. The total value of ecosystem services and biodiversity were calculated following the procedure previously outlined for rural regions. As before, the value of coastal recreation was not included in the analysis since all the selected regions are landlocked with the only exception of Ipeiros.

Table 4. Indicators of socio-economic condition, biodiversity richness and ecosystem services value in selected remote mountainous NUTS2 regions of Europe

NUTS2 region	GDP per capita, 2005 (US$/ person/ year)	Employment in primary sector, 2006 (% of total employment)	Unemploy ment rate, 2007 (% of population aged 15 and over)	Biodiversity index	Forest ecosystem service value (% of GDP)	Wetlands/fresh water ecosystem service value (% of GDP)
Yugozapaden (BG)	11,557	2.77	3.9	94.1	1.7	2.4
Centru (RO)	10,255	16.90	8.5	83.9	7.4	0.5
Ipeiros (GR)	19,185	19.21	10.0	75.2	1.5	15.3
Provincia Autonoma Bolzano/Bozen (IT)	36,805	0.00	2.6	77.5	2.0	2.0
Tirol (AT)	36,631	5.09	2.8	75.1	5.3	0.3
Vorarlberg (AT)	36,631	2.81	3.6	75.0	2.0	1.2
Salzburg (AT)	39,863	5.54	3.0	74.9	4.2	0.6

In addition to the indicators in Table 4, we evaluated the accessibility to large cities and exchange markets of the selected mountainous regions. For this purpose, we used a global map of accessibility that was developed by the Joint Research Center of the European Commission (http://bioval.jrc.ec.europa.eu/products/gam/index.htm) and that contains information on the travel time to the nearest city with population of 50,000 inhabitants or more in a 30 arc seconds resolution. As expected due to their geographical isolation, all the selected mountainous regions are in remote locations that are characterized by a low accessibility. The average travel time in the selected regions is 168 minutes, the least accessible of them being Provincia Autonoma Bolzano/Bozen with an average travel time equal to 215 minutes. The median and mean travel time in the 367 NUTS2 regions of Europe that were considered in this analysis are respectively 107 and 140 minutes.

Figure 9 illustrates the dependencies between the socio-economic, biodiversity and ecosystem value indicators in the selected remote regions. Each of the axes in the spider charts represents one of the indicators, with the values of the indicators standardized between 0 and 100.

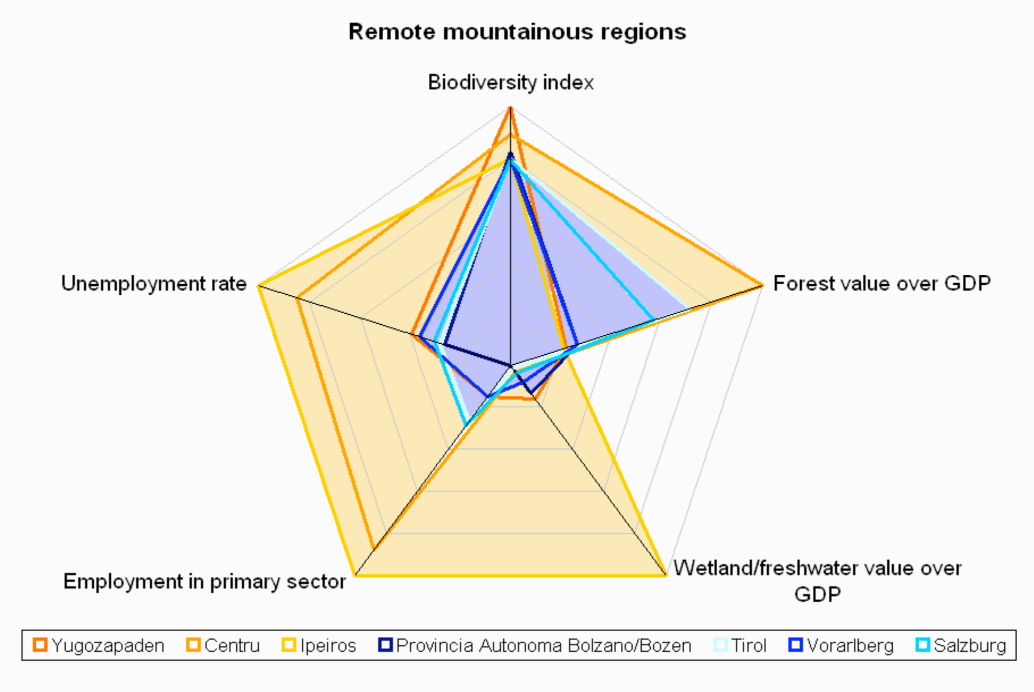


Figure 9. Linkage between ecosystem services value, biodiversity and socio-economic indicators in selected mountainous regions of Europe

The trends in the indicators in Figure 9 are qualitatively similar to what was found for rural regions, although the differences in some of the indicators are less marked. Unemployment rates and employment in the primary sector are higher in the considered poor remote regions and so are the values of the biodiversity indicator, although high biodiversity levels are found also in the high-income regions. Population density is relatively low in all considered regions and, on average, lower in low-income regions (72 inhabitants per square km versus 84 in high-income regions). On the other hand, the value of ecosystem services as percentage of the GDP is, on average, higher in low-income regions and is highest in Ipeiros for wetlands and freshwater ecosystems (15.26%) and in Centru for forest ecosystems (7.42%).

In general, the results for remote mountainous regions support the previous findings for rural areas in the sense that they confirm that poor communities are more reliant on ecosystem services and biodiversity than less vulnerable ones. The comparison with rural regions, however, highlights how remote mountainous regions are more homogeneous in terms of biodiversity levels, population density and ecosystem service values.

5.5 Conclusions and Policy Recommendations for the EU

In this paper, we have shown that the correlation between biodiversity, ecosystem services and the security of human livelihoods is complex and extremely varied across different economies. A spatial mapping of selected indicators of biodiversity, ecosystem services and human livelihoods demonstrates that large disparities exist in the degree of dependency on ecosystem services and, subsequently, in the levels of vulnerability to changes in or losses of biodiversity and the respective impacts in the provision of ecosystem services. There is also an imbalance for those most affected by, yet least able to respond to, the loss of ecosystem goods and services as well as the inequality in the global distribution of derived benefits. Notwithstanding the direction of causalities, it is the poorer segments of society that are both assumed to be most vulnerable to, and affected by, biodiversity degradation.

Our results show that the composition of the ecosystem service value for the selected European countries, calculated as percentage of GDP, vary across different countries and, more importantly vary among country-income categories, including high-income, medium-income and low-income categories. Among high-income countries, Finland and Sweden show the highest value of ecosystem services with respect to the national GDP. This is partly due to the large total area of wetland and freshwater ecosystems in these countries, which, despite the low per-hectare values. Secondly, the value of forest provisioning services in Sweden and Finland are particularly high, reflecting the fact that forestry is a widely practiced activity in these countries. In middle-income countries, relatively high values of forest ecosystems are found in countries that are landlocked or with a short coastline, such as the Czech Republic and Slovenia, while in the remaining countries high values are provided by wetlands and freshwater ecosystems and coastal recreation. In low-income countries, ecosystem service values tend to be high particularly for forests and, in Bulgaria and Croatia, wetlands and freshwater ecosystems. The high values of wetlands and freshwater ecosystems in Bulgaria and Croatia reflects the relatively high per-hectare values and the low GDP in those countries.

The paper also explored the relationship between ecosystem services, biodiversity and income-related vulnerability in more detail within Europe. First, we focus our analysis in rural agricultural areas and investigate the link between the livelihood of the rural poor, biodiversity and the provision of ecosystem services. In this context, we proposed to identify the possibility contours, which we define as social vulnerability contours maps, that relate human livelihoods, biodiversity richness and the level of ecosystem services. Among the three income categories, the narrowest boundaries are found in high-income countries. With the exception of Austria, France and Switzerland, the biodiversity levels are lower than the average values in middle and low-income countries. Moreover, the contribution of agricultural activities to the countries' economy is generally low, with the exception of Finland, where agriculture added value accounts for 3% of the GDP and 37% of the population lives in rural areas. In addition, ecosystem service values generally provide a small contribution to the economy of high-income countries, with the notable exception of Sweden and Finland where they account for 14% and 11% of the country's GDP. In middle-income countries one can notice an enlargement of the boundaries, with the added value of agriculture, rural population and biodiversity levels increasing compared to high-income countries. On the contrary, the largest possibility contours are found however in low-income countries where the highest levels of agricultural added value (10% in Romania), unemployment rate (11.1% in Slovakia) are found, suggesting a higher vulnerability of these economies to socio-economic and environmental shocks. Significantly, the highest values of biodiversity (91.3 in Bulgaria) and ecosystem service value over GDP (30% in Croatia) are also found in low-income economies. This suggests a large potential for biodiversity, mediated through the provision of ecosystem goods and services, to act as a positive stimulus for the countries' economy, create employment, and contribute to the livelihood and welfare of the populations.

Second, we focused our attention in a more explicit spatial scale and investigate the all NUTS2 regions in Europe with the highest density of agricultural land-use. For the calculation, all the grid cells identified as "agricultural areas" in Corine were considered, including arable land (i.e., non-irrigated, permanently irrigated and rice fields), permanent crops (i.e., vineyards, olive groves, fruit trees and berry plantations), pastures, and heterogeneous agricultural areas (i.e., annual crops associated with permanent crops, complex cultivation patterns, land principally occupied by agriculture with significant areas of natural vegetation, and agro-forestry areas). Among regions with agricultural land-use density of 70% or higher, the three NUTS2 regions with the lowest and highest GDP per capita in 2007 were selected. The three rural poor regions identified are Del-

Alfold and Eszak-Alfold in Hungary, and Lubelskie in Poland. In addition, and for the sake of a running a comparative analysis, the three rural regions with highest GDP per capita values among the regions with a strong agricultural land-use density are also selected. We refer to Southern and Eastern Ireland, Berkshire, Buckinghamshire and Oxfordshire in the United Kingdom, and Groningen in the Netherlands. The dependencies between the socio-economic, biodiversity and ecosystem value indicators in the selected rural regions differ substantially between the two groups of regions, despite the fact that both groups represent rural agricultural areas. In low-income regions, both the employment in the primary sector as a share of total employment and the overall unemployment rate are higher, suggesting that these areas are particularly vulnerable to socio-economic changes and environmental degradation. The low employment rate in high-income agricultural regions may be explained by the high level of mechanization of agricultural practices in these areas. On the other hand, biodiversity levels are substantially higher in low-income regions and the value of forest ecosystem services is particularly high when compared to the total GDP of these regions. This supports the hypothesis that the economic structure of vulnerable rural regions of Europe – such as the selected low-income, agricultural regions – is more strongly dependent on biodiversity and the provision of ecosystem services than that of richer areas, even if remote and predominantly agricultural.

Finally, we also investigate the role of biodiversity in the definition of social vulnerability contours maps by focusing our analysis in rural communities living in remote regions. Here, we focus on two types of remoteness: first we consider mountainous regions of Europe, as case-study for geographical remoteness, and second we look at distance from major cities as an indicator of the social dimension of accessibility. The results for remote mountainous regions support the previous findings, and respective social vulnerability contours maps, for rural areas in the sense that they confirm that poor communities are more reliant on ecosystem services and biodiversity than less vulnerable ones. The comparison with rural regions, however, highlights how remote mountainous regions are more homogeneous in terms of biodiversity levels, population density and ecosystem service values. However, unemployment rates and employment in the primary sector are higher in the considered poor remote regions and so are the values of the biodiversity indicator, although high biodiversity levels are found also in the high-income regions. Finally, population density is also lower in all considered regions and lower, on average, among the low-income regions. Communities living in regions with higher distances from major cities were also found to be more vulnerable than populations in more accessible regions. This is largely due to their lack of access to or the prices and affordability of substitute products and services. Isolation additionally limits coping strategies to deal with a deterioration of environmental services. Further, the location of rural households affects their potential to access markets or other sources of income from off-farm employment opportunities in neighboring urban areas.

Our finding confirms the earlier assumption that a biodiversity rich area is generally associated with a higher dependence on biodiversity and the provision of ecosystem services, which suggests that the local communities are more vulnerable to changing environment and losing biodiversity. Based on our definition of vulnerability and the socio-economic indicators used, people in low-income EU countries are more vulnerable than those in medium- and high-income countries. The following statistics are for the values of all of the socio-economic indicators in firstly high and then secondly low income countries: unemployment increased from 5.3 to 7.3%, rural percentage of the population from 22 to 37% and dependence of GDP from the agricultural sector from 1.5 to 5.9%. Ecosystem services account for 11.8% of the GDP in low-income countries in comparison with 3.6% for high-income countries. Specifically, the highest levels of agricultural added value (10% in Romania), unemployment rate (11.1% in Slovakia), biodiversity value (91.3 in Bulgaria) and ecosystem service value over GDP (30% in Croatia) were found in low-income countries, illustrating that the high levels of biodiversity could offer opportunities, if well managed, to improve the situation. Communities living in remote regions were also found to be more vulnerable than populations in more accessible regions. This is largely due to their lack of access to or the prices and affordability of substitute products and services. Isolation additionally limits coping strategies to deal with a deterioration of environmental services. Further, the location of rural households affects their potential to access markets or other sources of income from off-farm employment opportunities in neighboring urban areas.

Therefore, the complex linkages and trade-offs between biodiversity, ecosystem services, employment and the impacts on vulnerable groups do not allow for one single simple policy approach (no silver bullet!) to improve conditions both for nature and people. Moreover, the social aspects of biodiversity are not addressed by a specific policy, but rather constitute cross-cutting issues that affect a wide range of policies on different scales. Many other studies have shown that the protection of biodiversity and ecosystems cannot be restricted to nature protection policies only, but instead have to be mainstreamed across different policies and sectors. By expanding the scope to include the even more complex interactions between biodiversity and the enhancement of jobs and of livelihoods in vulnerable areas, the range of relevant policies becomes even larger.

Recent debate in the European Commission placed increased emphasis on the importance of green infrastructure for multi benefits to the economy[27]. Green infrastructure can be defined as the distribution of natural capital that benefits society through the provision of ecosystem services (TEEB, 2010), which may take the form of climate regulation, water purification, and space for recreation. Green infrastructure is likely to become a key component of the delivery of the new biodiversity target for 2020, and could play a decisive role in integrating biodiversity into other policies such as agriculture, forestry, water, transport and regional and cohesion policy[28], as it demonstrates the contribution that biodiversity can make to these policy areas. The debate has important implications for biodiversity as the provision of the services relies on the ecosystems being in good condition requiring intervention to ensure they are of an appropriate size, condition and not impacted by fragmentation.

In addition, EU regional policy aims to reduce the gaps in well-being between regions and ensure coherent and fair economic development within the EU. The policy is financed through structural funds and the cohesion fund and constitutes 35% of the EU budget for the spending period 2007-2013 (€348 billion)[29]. The funds finance a variety of measures, including transportation infrastructure, urban regeneration and rural development. While activities can cause significant deterioration of biodiversity through the fragmentation of landscapes and habitats (Kettunen et al, 2007), the funds provide important funding opportunities for biodiversity conservation such as the development of infrastructure linked to biodiversity and investments in Natura 2000. Projects must, however, demonstrate a contribution to the broader sustainable socio-economic development of the region in which they are based. Indeed, the prevention of environmental risks is one of the priorities of structural funds, offering the possibility for funding actions to maintain or restore the capacity of ecosystems to mitigate flooding, wild fires and drought risks (Kettunen et al, 2009). In other cases, opportunities exist for the investment in facilities to promote nature-based tourism, with potential positive impacts on economic development of disadvantaged areas and on biodiversity (see EEA, 2009).

Despite these opportunities, uptake of measures supporting biodiversity under structural and cohesion funds have been limited. This can be partly attributed to the bureaucracy and administration burden of accessing the funds (Torkler et al, 2008) and the lack of absorption

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[27] 'EC workshop: towards a green infrastructure for Europe', March 2009. Workshop proceedings are available at: http://www.green-infrastructure-europe.org/

[28] http://ec.europa.eu/environment/nature/info/pubs/docs/greeninfrastructure.pdf

[29] http://europa.eu/scadplus/glossary/structural_cohesion_fund_en.htm

capacity in recipient regions to utilise the funds (EEA, 2009). An additional issue is that the decision on how the funds are to be spent is made entirely at Member State level, which means that despite the opportunities that exist to fund biodiversity and social cohesion projects, there is no means at the EU level to ensure this happens. Moving forward, DG REGIO is likely to align the Cohesion fund more with the priorities of Europe 2020, which could have a negative impact for biodiversity which does not feature in the strategy (McConville and Gantioler, 2010).

The next financing period (2013-2019) still provides an opportunity to ensure that regional policy has a positive impact on biodiversity and social cohesion but it will require changes to the current financing process. This may include, as implemented in Austria, that structural funds should have no net negative impact on the environment (EEA, 2009). In addition, there could be clear ear-marking a proportion of the funds for the financing of biodiversity within the funds and there may be opportunities for increasing the Commission's oversight of the national implementation of the funds to ensure better allocation of financial support towards biodiversity. Ultimately, there will have to be a stronger case made for the ecosystem service benefits provided by nature, the protection of which may come from the mainstreaming of green infrastructure approaches to land management.

CHAPTER 6 CONCLUSIONS

The dissertation constituted four research papers that have been presented in chapter 2, chapter 3, chapter 4 and chapter 5, corresponding to the four objectives set out earlier in Chapter 1. This final chapter draws together the main conclusions by providing a summary of the findings of each chapter in Section 6.1. Section 6.2 discusses the policy implications of the findings. Section 6.3 points out the limitations of the present study and sets out some ideas for future research in this area.

6.1 Research Conclusions

Chapter 2: *Valuing the Climate Change Impacts on European Forest Ecosystems into the Future.*

[Methodology]

This paper reported an original economic valuation of climate change impacts on forest ecosystem goods and services that biodiversity underpinned. On the one hand, we provided a comprehensive classification and mapping of the different European countries according to their contribution in the supply of forest goods and services. The proposed analysis was anchored in the well-known classification proposed by the MA approach. On the other hand, we investigated the role of each country in detail, providing forest provisioning services, regulating services and cultural services.

In order to value the climate change impacts, we first identified four different climate scenarios, which are referred to the A1FI, A2, B1 and B2 scenarios, corresponding to the four IPCC storylines, and evaluated here to the year 2050. Secondly, we proceeded with the analysis and evaluation of climate change impacts on the total forest area (for each country), as well as, on the provisioning quantities (in bio-physical terms) across all forest goods and services under consideration. The projections of future trends of forest areas and the provision of wood forest products in 2050, in terms of four IPCC storylines, were derived from climate models, including HadCM3, and simulating the response of the global climate system to increase greenhouse gas concentrations. Moreover, considerable impacts of differentiated latitudes on the variability of forest EGS were taken into account by carefully regrouping the 34 selected countries located in different latitude intervals. As a consequence, it enabled us not only to identify the respective forest productivity related to predominant forest types situated in each latitude interval, but also to assess and compare the sensitivity of the differentiated forest types in response to climate change impacts. Both of these aspects have been considered when projecting the future trends of forest area and forest product flows by 2050, in terms of the four IPCC storylines. Finally, we applied various economic valuation methods (including market and non-market valuation methods, primary and value transfers methods) to estimate the values of the three MA service categories involved, i.e. the provisioning services, regulating services and cultural services provided by European forests.

[Results]

The obtained results suggest that the impact of the climate change on biodiversity, and its welfare evaluation in terms of the respective changes on the provision of forest ecosystem goods and services, is multifaced. First, it depends on the nature of the forest good and service under consideration, with carbon sequestration ranked as the most valuable service. Moreover, cultural values reveal to be more sensitive to the four IPCC scenarios than the values of other ecosystem services, while the wood forest products as the most resilient to climate change. Second, the distributional impacts of climate change on the provision of these goods and services also depend on the geo-climatic regions under consideration. In other words, these impacts are not distributed uniformly across the European countries under consideration. Third, the choice of future development path has an essential role in regulating future climate and determining the values of various ecosystem goods and services. The B-type scenarios (the most sustainable sound future scenarios), in particular the B1 scenario, are found associated with the highest levels of provision in all of the ecosystem services under consideration, i.e. wood products, carbon sequestration and cultural services. For example, our results show that cultural services provided by forest ecosystems have their highest levels in the Mediterranean countries, ranging from 8.4 to 9.0 billion dollars, respectively, in the B2 and B1 scenarios, to 3.9 to 4.8 billion dollars, in the A1 and A2 scenarios.

Moreover, by conducting a comparative analysis of the future IPCC scenarios, we are able to compare the welfare impacts resulted from different assumptions on a number of factors that impose pressures on forest ecosystems, including economic growth, mounting population and climate change. For example, the Mediterranean Europe can assist to a welfare gain amounting to an 86% increase in the cultural values when moving from an A2 scenario (regional economic scenario - the baseline) towards a B2 scenario (regional sustainable scenario). This is followed by an increase of 45% in the value of the carbon sequestration services and a 24% increase in the value of the wood provision services. In other words, not adopting a B2 storyline, but instead moving towards an A2 scenario, will be associated to a high welfare loss in Mediterranean Europe owing to the reduced quantity and quality of the forest ecosystem services under consideration. Alternatively, moving from an A2 scenario towards an A1 (global economic scenario) scenario will always involve a welfare loss for Mediterranean Europe. In short, Mediterranean Europe scenarios will always be associated to a reduced quantity and quality of forest ecosystem services and thus, result in loss of human welfare. On the contrary, storyline B1 (global sustainable scenario) is ranked as the most preferred scenario for this geo-climatic area.

All in all, the estimated economic magnitudes of climate change impact on forest ecosystems contribute to a better understanding of the potential welfare losses across different regions and to the identification of winners and losers as a result of future climate change. In addition, they can also improve the existing numerical estimation of the total costs of climate change to human society, by counting for not only the reduced productivity and revenues in relevant economic sectors, but also the lost economic values due to biodiversity extinction and ecosystem degradation. These therefore have very important policy implications to reallocate resources among Europe countries to cope with the continuous climate change.

Chapter 3: *When Micro- and Macro-Economics Meet together to Reveal the True Value of Climate Change Impact, Conflicts or Complement?*

[Methodology]

This paper explored the potential to incorporate micro- and macro- economic analysis in the estimation of the socio-economic impacts of climate change-induced changes in biodiversity and ecosystems. Biodiversity and ecosystem services were interpreted as important components of the world economic system. In this study, we tried to incorporate ecosystem services into a macro economic mechanism, where the world economy was assessed by a set of computable general equilibrium (CGE) models. Within this framework, changes in carbon sequestration provided by European forests were incorporated into a CGE model through a global warming approach, which allowed the consideration of climate change impacts on forest carbon sequestration services and to re-compute a temperature equivalent induced by the higher release of CO2 emissions in the atmosphere resulting from climate change. On the basis of this new information, we then re-estimated all of the climate change impacts considered using the CGE model and recalculated new macro-regional GDP effects. The differences between climate change impacts on GDP considering the original and the new carbon sequestration levels were used as an approximation of the general equilibrium value of the changes in the European forest carbon sequestration service.

This innovative approach allowed us to explore the scaling-up potential of regional climate change impacts on biodiversity and ecosystem services and to identify the winners and losers of climate change impacts at a larger geographic scale.

[Results]

In summary, the present estimation GDP value estimates confirm that (1) climate change brought along significant welfare impacts, (2) biodiversity and ecosystem services played an important role in the determination of the final welfare magnitudes, and (3) not all European countries would have identical impacts, some countries might lose more than others, and some countries might gain, depending on their geographical location, the existing markets and profile with respect to biodiversity indicators and land use patterns. Therefore understanding the magnitudes of welfare impacts is important for results in the design of any climate-mitigation, or adaptation, policies.

However, it is important to note that our study only signals the tip of the iceberg, for the present analysis only focused on biodiversity anchored in a single ecosystem type, i.e. forest ecosystem, and considered only a single ecosystem service produced by forests, carbon sequestration. If taking into account (1) the 34 European countries and (2) the sequestration services from forests alone, climate-change-cause impacts on biodiversity and ecosystem services are responsible for welfare loss amounting to 85 billion USD$. If we consider the World Bank's global ranking with respect to GDP per capita, this amount corresponds to the aggregated GDP of the 22 poorest countries, which constitute 13% of the totality of world countries. Nonetheless, if we also add (3) the biodiversity productivity effects on the agricultural sectors, (4) freshwater and coastal ecosystems, the total loss in GDP terms will be much higher. These results lead to the main conclusion that autonomous adaptation cannot be invoked as the solution to climate change, but needs to be addressed with proper mitigation and planned adaptation strategies.

Moreover, we should also recognize the dynamic aspect of ecosystem changes in response to direct and indirect socio-economic drivers, Today, Europe, along with many other countries, experiences the growing pressures from population growth, changing diets, urbanization, and climate change, which are causing continuous ecosystem degradation and biodiversity decline. In return, the changes in biodiversity and ecosystem cannot directly affect only our economic system, but also the capacity of natural ecosystems to mitigate and adapt to further climate change. These are externalities have already been impacting the conventional economic systems. Therefore, fully assessing the costs of these externalities, in particular the costs of losing biodiversity are important for the design of effective policy instruments to correct the failed market signals and to fully incorporate the costs of climate change into the economic mechanism. This way will enable us to prevent from further resource degradation and fight against climate change.

Chapter 4: *Modelling the links between biodiversity, ecosystem services and human wellbeing in the context of climate change: results of an econometric exercise to the European forests.*

[Methodology]

This paper attempted to model the relationships between climate change, biodiversity and the value of ecosystem services with a specific emphasis on the climate change included biodiversity effects in European forests. The research began with the construction of a composite biodiversity indicator that integrated quantitative and qualitative changes of biodiversity projected under different future climate scenarios. This indicator incorporated in-depth socio-economic reasons of biodiversity changes, along with climate change impacts was expected to be a simple but comprehensive biodiversity measure to analyze the climate change induced biodiversity effects and the resulting socio-economic impacts. In the present study, we tried to make the best use of existing data released by a large number of IPCC data distribution centers, regarding the projected trends of population growth, economic development, future species richness and increase in local temperature under different future climate scenarios. Values of ecosystem services were derived from a most recent assessment study on the climate change impacts on forest ecosystems in Europe (Ding *et al.* 2010). Furthermore, the paper explored the use of 3SLS regression to simultaneously estimate (1) the determinants of economic value of ecosystem services; (2) the determinants of land-use changes (i.e. the changes of forest-land cover); (3) the determinants of changes in biodiversity. The investigation was conducted first in a baseline model, where a global effect of climate change was considered, followed by regressing a modified model, in which the regional effects of climate change impacts were counted for.

[Results]

In summary, the results of the present research suggest that a composite biodiversity indicator, integrating information about changes in species and habitats, can serve as a better option than the individual biodiversity indicators for measuring and predicting the trends of biodiversity changes in response to a set of climate and socio-economic drivers in different future climate change scenarios. For instance, in the present study, the average score of future biodiversity status (reflecting either improvement or degradation of biodiversity) is derived from the projected future trends of four different species, i.e. tree, plant, bird and herptile as well as the changes in forest habitats under different future climate scenarios, therefore the composite biodiversity indicator indicates an overall improvement or degradation of the forest ecosystems in each of the 17 EU member states in a climate change context. In this context, we are more confident to use this indicator to describe and measure the health of forest ecosystems under different climate conditions and to analyze the respective changes in its capacity of delivering ecosystem goods and services. Moreover, the structure of the composite biodiversity indicator is so simple that it can be easily used for communicating with policymakers and the broader audience.

Moreover, our results from the 3SLS regression suggest that rising temperature negatively affects biodiversity and ecosystem conditioning at an accelerating rate across geo-climatic regions in the future. In addition, we also found a strong relationship between temperature and the value of ecosystem services, but the direction of this relationship depends on the type of ecosystem services under consideration. That is to say, every 1ºC increase in temperature will contribute proportionally to the changes of the value of ecosystem services. Independent from the consideration of spatial effects of climate change, rising temperature is found positively impacting the value of provisioning and regulating services, but negatively related to the cultural services. Furthermore, the spatial effect of climate change induced biodiversity changes is captured, by introducing a cross-effect between biodiversity and temperature in the model.

All in all, our results show that biodiversity and temperature can perform together as either "complimentary" or "substitute" factors to affect the supply as well as the value of certain types of ecosystem goods and services. For example, in the case of provisioning services provided by Mediterranean forests, we find a clear "complementary" effect between biodiversity and temperature. Our results suggest that the negative impacts of climate change on biodiversity will go against the positive direct climate change impact on the Mediterranean forests, and thus generate a net negative impact on total value of provisioning services in the future. More specifically, biodiversity loss caused by increment of 1ºC in the temperature is responsible for at least 49% in every one-dollar reduction of the value of forest provisioning service in the Mediterranean forests. Whereas the substitute effect between biodiversity and temperature refers that climate change induced biodiversity effects on EGS may attenuate/decrease the negative direct climate change impact in some regions, where biodiversity plays a key role in mitigating the those negative impacts of climate change. For instance, this is clear for the cultural services provided by the Mediterranean forests, in which the reduction of 1ºC in the temperature is responsible for half of every 1% improvement of biodiversity indicator score. The latter will consequently contribute to nearly 28% of every additional one-dollar value generated in the cultural services provided by Mediterranean forests. Similar result is found also for the regulating services in the region, where biodiversity richness is expected to have a significant role in determining the respective values.

Chapter 5: *The social dimension of biodiversity policy in the European Union: valuing the biodiversity benefits to vulnerable groups*

[Methodology]

This paper explored the use of spatial mapping tools, such as Geographic Information Systems (GIS) to explore the social dimension of biodiversity policy, so as to identify and analyze the strength of the linkage between biodiversity and human livelihoods at different geographic locations. Our analysis focused on a European scale, where biodiversity and ecosystem benefits have been well studied for many ecosystems and concentrates in particular on forest, coastal and wetland ecosystems both at country level and downscaled to a higher geographical resolution. Moreover, the data on socio-economic and biodiversity conditions of the countries under consideration were also well documented in the literature. These three types of information were mapped in a spatial gradient. The results of this study could provide important insights for the EU policymakers to design potential policy instruments that could on the one hand promote biodiversity conservation and prevent natural resources from degradation, and on the other hand contribute to social stability and human livelihoods (e.g. increased number of jobs in the protected area and/or ecosystem-related economic activities).

[Results]

The results of this paper show that the correlation between biodiversity, ecosystem services and the security of human livelihoods is complex and extremely varied across different economies. A spatial mapping of selected indicators of biodiversity, ecosystem services and human livelihoods demonstrates that large disparities exist in the degree of dependency on ecosystem services and, subsequently, in the levels of vulnerability to changes in or losses of biodiversity and the respective impacts in the provision of ecosystem services. There is also an imbalance for those most affected by, yet least able to respond to, the loss of ecosystem goods and services as well as the inequality in the global distribution of derived benefits. Notwithstanding the direction of causalities, it is the poorer segments of society that are both assumed to be most vulnerable to, and affected by, biodiversity degradation.

Our results also show that the compositions of the ecosystem service value for the selected European countries, calculated as percentage of GDP, vary across different countries and, more importantly vary among country-income categories, including high-income, medium-income and low-income categories. Among high-income countries, Finland and Sweden show the highest value of ecosystem services with respect to the national GDP. In middle-income countries, relatively high values of forest ecosystems are found in countries that are landlocked or with a short coastline, such as the Czech Republic and Slovenia, while in the remaining countries high values are provided by wetlands and freshwater ecosystems and coastal recreation. In low-income countries, ecosystem service values tend to be high particularly for forests and, in Bulgaria and Croatia, wetlands and freshwater ecosystems. The high values of wetlands and freshwater ecosystems in Bulgaria and Croatia reflect the relatively high per-hectare values and the low GDP in those countries.

Furthermore, our analysis in rural agricultural areas suggests that among the three income categories, the narrowest boundaries are found in high-income countries. For example, the contribution of agricultural activities as well as ecosystem services to the countries' economy is generally low in high-income countries, with the exception of Finland and Sweden. In middle-income countries one can notice an enlargement of the boundaries, with the added value of agriculture, rural population and biodiversity levels increasing compared to high-income countries. On the contrary, the highest values of biodiversity (91.3 in Bulgaria) and ecosystem service value over GDP (30% in Croatia) are found in low-income economies. This suggests a large potential for biodiversity, mediated through the provision of ecosystem goods and services, to act as a positive stimulus for the countries' economy, create employment, and contribute to the livelihood and welfare of the populations. Moreover, our results show that in low-income regions, both the employment in the primary sector as a share of total employment and the overall unemployment rate are higher, along with substantially high biodiversity levels and higher share of the value of forest ecosystem services in the total GDP of these regions. This supports the hypothesis that the economic structure of vulnerable rural regions of Europe – such as the selected low-income, agricultural regions – is more strongly dependent on biodiversity and the provision of ecosystem services than that of richer areas, even if remote and predominantly agricultural. Finally, the results for remote mountainous regions support the previous findings that poor communities are more reliant on ecosystem services and biodiversity than less vulnerable ones. The comparison with rural regions, however, highlights how remote mountainous regions are more homogeneous in terms of biodiversity levels, population density and ecosystem service values.

6.2 Policy Implications

This doctoral dissertation is inspired by the major environmental and socio-economic challenges faced by biologists, climate scientists, economists and policymakers today, and is dedicated to the state-of-the-art literature in the cross-cutting research area where biodiversity economics and climate economics blend. The present work constituted methodologies that were anchored in the neoclassical macro- and micro- economic theory and explored the use of modern techniques to seek solutions to the most challenging policy questions, such as how does climate change affect human well-being through biodiversity and ecosystem functioning? How does the spatial mapping of climate change induced social-economic consequences look like? How does economic valuation of biodiversity and ecosystems support policymaking to mitigate climate change impacts globally and to achieve sustainable development goals locally? And how to develop cost-effective market mechanisms to deal with the distributive and equity issues related to climate change impacts and ecosystem services benefits? With these policy questions in mind, the methodologies developed in this dissertation have gone beyond conventional economic valuation of natural environment/capital. Every piece of work included in this dissertation was characterized, to certain extent, by highly innovative features, including the integration of micro-and macro-economic models, the spatial analysis of climate change impacts on biodiversity, ecosystem services and human wellbeing, the creation of new biodiversity metrics to measure welfare changes in a climate change context, and the use of geographic information system (GIS) for visualizing the links between biodiversity benefits and human livelihoods.

From a practical perspective, we explore different angles of economic theory incorporated with knowledge generated in other disciplines, such as climate science, biology, social and political science, so as to better understand the dynamics and complexity of climate change impacts and to translate these impacts from biophysical terms, measured by e.g. loss of ecosystem services into monetary metrics that can be used for policy aiding. In particular, this work is conducted by (1) developing a holistic, well-accepted approach that explores the mapping of complex links between climate change, biodiversity, ecosystem services and human welfare in numerical terms; (2) further extending the state-of-the-art methodologies so as to monetize the climate change induced impacts on biodiversity, ecosystem services and human wellbeing; and, (3) promoting and discussing the incorporation of the valuation results into the support of policy making, including ecosystem-based climate change mitigation policy instruments (such as the Reducing Emissions from Deforestation and forest Degradation - REDD initiatives) as well as ecosystem-based welfare re-distributional policy instruments (such as the Payment for Ecosystem Services - PES).

Moreover, all the methodologies are applied to the European forest ecosystems, where we demonstrate how to assess climate change impacts on forest ecosystems as well as the associated welfare effects. In general, the conducted economic valuation of climate change impacts on a variety of forest ecosystems and ecosystem services in total 34 European countries has revealed the complex nature and non-linearity of climate change impacts at different geographical scales, across populations and in different future development paths. In addition, the integration of CGE model with the hybrid economic valuation model provides some insights on the magnified global effects of climate change impacts on the regional biodiversity and ecosystem services, and demonstrates the important role of ecosystem services, such as forest carbon sequestration services, in regulating climate and affecting global GDP. Furthermore, by employing an econometric model, we find that relationships between climate change, biodiversity, ecosystem services and human well-being are unevenly distributed across geo-climatic regions, and the magnitudes of these impacts vary depending on the type of ecosystem services under consideration. Finally, the study on social dimension of biodiversity policy explores the spatial mapping of the coincidence of ecosystem services and human livelihoods and finds that there are obvious synergies between socio-economic policies (e.g. job creation) and biodiversity policies (e.g. biodiversity conservation).

Notwithstanding the uncertainty issues related to climate change, our assessment of the climate change impacts has shown some interesting results that are potentially useful for policy implications.

First of all, there is obviously a need for optimal forest management strategies in Europe to cope with climatic shocks on the regional ecosystems and to promote the sustainable use of forest resources for satisfying long-term human demand. However, the design and implementation of these policies should respect the specific local environmental, economic and political context of each country. In other words, there are no *silver bullet* policies that can be applied to the European context as a whole. This refers to a bottom-up management approach to effectively manage forest resources at country level. On the other hand, by comparing the welfare gains/losses of climate change impacts occurred in different geo-climatic regions, the EU will be able to evaluate the cost-efficient policy alternatives across all of the member countries. Therefore, the countries that suffer the most losses from climate change may be compensated through other supplementary policy package imposed by the EU. This infers a top-down approach to improve the overall efficiency of resource management in Europe. Thus, the recognition of the economic values of biodiversity and ecosystem services are essential in terms of identifying conservation priorities, allocating the limited resources for conservation, and guiding the cost-effective and efficient policymaking across regions.

Second, we should also recognize the dynamic aspect of ecosystem changes in response to direct and indirect socio-economic drivers, including climate change. Today Europe, along with many other countries, experiences the growing pressures from population growth, changing diets, urbanization, and climate change, which in turn are causing continuous ecosystem degradation and biodiversity decline. In return, the changes in biodiversity and ecosystem can directly affect not only our economic system, but also the capacity of natural ecosystems to mitigate and adapt to further climate change. These are externalities have already been impacting the conventional economic systems over the last decade. Therefore, fully assessing the costs of these externalities, in particular the costs of losing biodiversity are important for the design of effective policy instruments to correct the failed market signals and to fully incorporate the costs of climate change into the economic mechanisms. This way will enable us to better understand the welfare effect of climate change, to prevent from further resource degradation and to effectively fight against climate change.

Third, our results show that biodiversity and temperature can perform together as either “complimentary” or “substitute” factors to affect the supply as well as the value of certain types of ecosystem goods and services (EGS). In the case of provisioning services provided by Mediterranean forests, we find a clear “complementary” effect between biodiversity and temperature. Our results suggest that the negative impacts of climate change on biodiversity can go against the positive direct climate change impact on the Mediterranean forests, and thus generate a net negative impact on total value of provisioning services in the future. Whereas the “substitute” effect between biodiversity and temperature refers that climate change induced biodiversity effects on EGS may attenuate/decrease the negative direct climate change impact in some regions, where biodiversity plays a key role in mitigating the those negative impacts of climate change. These results may imply some important synergies of the climate and biodiversity policies. In other words, although climate change may have directly negative impacts on the value of ecosystem services, it is possible to mitigate these negative impacts by better managing biodiversity and natural resources. In many cases, the benefits derived from biodiversity can be large enough to compensate the loss of ecosystem productivities and values as a result of climate change.

Finally, results from studying the complex linkages and trade-offs between biodiversity, ecosystem services, employment and the impacts on vulnerable groups do not allow for one single simple policy approach (no *silver bullet*!) to improve conditions both for nature and people. Moreover, the social aspects of biodiversity are not addressed by a specific policy, but rather constitute cross-cutting issues that affect a wide range of policies on different scales. Many other studies have shown that the protection of biodiversity and ecosystems cannot be restricted to nature protection policies only, but instead have to be mainstreamed across different policies and sectors. By expanding the scope to include the even more complex interactions between biodiversity and the enhancement of jobs and of livelihoods in vulnerable areas, the range of relevant policies becomes even larger. For example in Europe, the European Commission has placed increasing emphasis on the importance of green infrastructure for multi benefits to the economy. While some activities can cause significant deterioration of biodiversity through the fragmentation of landscapes and habitats (Kettunen et al, 2007), but at the same time, the new policies also provide important funding opportunities for biodiversity conservation such as the development of infrastructure linked to biodiversity and investments in Natura 2000. In other cases, opportunities exist for the investment in facilities to promote nature-based tourism, with potential positive impacts on economic development of disadvantaged areas and on biodiversity (see EEA, 2009). To conclude, valuing ecosystem services and comparing the benefit associated with conservation of natural areas with the benefits from conservation can provide useful information for setting priorities in a variety of contexts.

6.3 Limitations and Future Research

To the best of our knowledge, the present doctoral dissertation represents the first attempt to systematically assess the loss of human welfare with respect to changes in biodiversity and forest ecosystem services which are directly driven by climate change. However, we acknowledge the complexity in mapping, modeling and estimating the relationships between climate change, biodiversity, ecosystem functioning, ecosystems services and human well-being. In fact, many ecosystem services, such as the supporting services cannot be captured by any economic valuation techniques, neither be projected for future scenarios. In particular, we recognize that the value estimates reported for regulating services in the present paper are underestimated, as we do not consider other regulating services, e.g. watershed protection and soil nutrient cycling, due to the limited knowledge about how to quantify those services in physical terms and how to project their changes with respect to future climate change. Against this background, we subscribe to the ongoing 'Potsdam Initiative' for biodiversity, also suggesting that it is imperative to continue further with a global study so as to have a better understanding of the linkages between biodiversity and human well being, especially in the context of global change.

As for the new partial-general model perspective, it is possible to extend the analysis in several dimensions. Firstly, the CGE world model is being fed only with EU micro-economic valuation data on ecosystems services. The main reason for this is that global circulation models are not widely available in the assessment of worldwide climate change impacts on biodiversity and ecosystem services. The consequence is that the current analysis is not able to disentangle additional and potentially significant interactions triggered by climate-change impacts on ecosystem services occurring outside the EU[30]. Because part of the CGE modelling potential remains unexploited, the next step is inevitably the design and assessment of a full general equilibrium model that embraces worldwide climate-change impacts on biodiversity and ecosystem services. Secondly, from the point of view of technical design, the model faces significant limitations in the capture of certain values of ecosystems services. For instance changes in forest timber production by hectare do not necessarily translate into the same productivity change in commercial raw wood input for timber industry. Similarly, changes in land productivity are not necessarily equal to changes in cultivated land productivity as now considered. Input information is aggregated at a higher geographical detail and is assumed to be uniform across sectors; this may hide relevant feedbacks. Irreversibility and thresholds in ecosystem functioning are not considered. Therefore, further work should be developed in order to explore with greater detail these different aspects of valuation transmission mechanisms of ecosystem services. Thirdly, it is highly recommended that the present analysis is extended beyond provisioning and regulating services to also consider cultural values provided by ecosystem services. This will be a challenging exercise due to the significant non-market nature of these valuation benefits. For these reasons, these results, contingent upon the available scientific information and considered within the global socio-economic context, can only be interpreted as the tip of the iceberg. These estimates should therefore be considered at best a lower bound to an unknown value of ecosystem goods and services.

Finally, when constructing the new biodiversity measure, i.e. the composite forest biodiversity indicator, we are also aware of certain limitations. For instance, the construction of the composite biodiversity indicator in this paper is subject to a significant lack of data that cover time-span long enough to describe the evolution of species from the past to the future under different climate change scenarios. As a consequence, we may observe an increase of species richness as well as forest habitats in many countries under the climate change scenarios by 2050 with respect to a baseline year of 2000, owing to the significant efforts of the EU-17 in moving towards more

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[30] For this reason, we label the present analysis as a partial-general equilibrium model, describing the potential general equilibrium effects of a set of regionally bound climate change impacts.

sustainable forest management practice. Thus, it is difficult for us to interpret, to what extent, the projected trends of changes in species richness is a result of the climate change impacts or a combination of different factors. Obviously, there is a need of incorporating more information about species richness from the far distant past into our current database, as a large time-span will enable us to rule out many other socio-economic factors other than the direct impact of climate change that affect biodiversity and ecosystem functioning. Finally, a richer historical data can also improve the overall performance of the econometric model and help us to better understand the cross-effects between biodiversity and temperature as well as the pattern in which they affect the ecosystem service values.

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ACRONYM

ATEAM	Advanced Terrestrial Ecosystem Analysis and Modelling
CASES	Cost Assessment of Sustainable Energy Systems
CBD	United Nations' Convention on Biological Diversity
CGE	computable general equilibrium
CIS	center for International earth science Information network, at the earth Institute at Columbia University in New York city
CO_2	Carbon dioxide
COP	Conference of the Parties
DICE	the Dynamic Integrated Climate Economy model
DPSIR	Driving forces-Pressure-State-Impact-Response
EGS	ecosystem goods and services
EU	the European Union
FAO	The Food and Agriculture Organization of the United Nations
FRA	the Global Forest Resources Assessments
FUND	the climate Framework for Uncertainty Negotiation and Distribution model
GCM	Global Climate Models or General circulation models
GDP	Gross Domestic Production
GHG	green house gas
GIS	Geographic Information Systems
HadCM3	Hadley Centre Couplet Model Version 3
IAMs	Integrated Assessment Models
IMAGE	Integrated Model to Assess the Greenhouse Effect
IPCC	Intergovernmental Panel on Climate Change
MA	Millennium Ecosystem Assessment
MCPFE	Ministerial Conference on the Protection of Forests in Europe
MERGE	Model for Estimating the Regional and Global Effects of greenhouse gas polices.
NCI	Natural Capital Index
NPP	net primary production
NWFPs	Non-Wood Forest Products
PAGE	An integrated assessment model incorporating the IPCC's five reasons for concern
PPP	Purchasing power parity
REDD	Reducing Emissions from Deforestation and Forest Degradation
RICE	Regional Integrated model of Climate and the Economy
SFM	sustainable forest management
TEEB	The Economics of Ecosystems and Biodiversity study
TEV	total economic values
WFPs	Wood Forest Products
WTP	Willingness To Pay
NPV	Net Present Value
GTAP	Global Trade Analysis Project
NUT2	Nomenclature of Territorial Units for Statistics
IUCN	the International Union for Conservation of Nature
UNDP	United Nations Development Programme
UNEP-WCMC	World Conservation Monitoring Centre of the United Nations Environment Programme

APPENDIX

Table A1a: Projection of European Forest Areas (Estimates in 1000 ha)

Latitude	Country	2005[a]	2050 A1FI[b]	2050 A2[b, c]	2050 B1[b]	2050 B2[b]
35 to 45	Greece	3 ,752	2,292	2,360	3,762	3,598
	Italy	9,979	8,346	8,253	11,677	11,893
	Portugal	3,783	2,170	2,174	3,254	3,283
	Spain	17,915	12,052	11,969	17,389	17,633
	Albania	794	519	835	918	991
	Bosnia and Herzegovina	2,185	1,476	2,372	2,609	2,817
	Bulgaria	3,625	2,279	3,664	4,030	4,351
	Serbia and Montenegro	2,694	1,789	2,876	3,163	3,415
	Turkey	10,175	6,788	10,912	12,002	12,959
	TFRY Macedonia	906	612	984	1,082	1,168
	Regional Total	55,808	38,324	46,399	59,885	62,108
45 to 55	Austria	3,862	5,298	5,177	5,199	5,471
	Belgium	667	526	545	698	842
	France	15,554	15,094	16,056	20,080	21,926
	Germany	11,076	10,049	10,075	12,696	14,033
	Ireland	669	442	379	638	656
	Luxembourg	87	80	78	103	94
	Netherlands	365	151	421	333	413
	Switzerland	1,221	1,985	1,913	2,113	2,121
	Croatia	2,135	1,438	2,311	2,542	2,745
	Czech Republic	2,648	1,781	2,863	3,149	3,400
	Hungary	1,976	1,288	2,070	2,277	2,458
	Poland	9,192	6,118	9,834	10,816	11,679
	Romania	6,370	4,299	6,911	7,601	8,207
	Slovakia	1,929	1,297	2,085	2,294	2,477
	Slovenia	1,264	837	1,345	1,479	1,597
	Regional Total	59,015	50,682	62,064	72,017	78,118
55 to 65	Denmark	500	414	677	434	839
	UK	2,845	1,986	2,145	2,780	3,476
	Estonia	2,284	1,515	2,435	2,678	2,892
	Latvia	2,941	1,948	3,132	3,445	3,719
	Lithuania	2,099	1,364	2,193	2,412	2,604
	Regional Total	10,669	7,227	10,582	11,749	13,530
65 to 71	Finland	22,500	18,224	17,999	16,517	17,079
	Iceland	46	30	29	28	28
	Norway	9,387	6,478	6,277	5,141	5,761
	Sweden	27,528	22,704	22,198	25,884	22,704
	Regional Total	59,461	47,435	46,503	47,569	45,572

Notes: [a] data from FAO; [b] projections by ATEAM and CLIBIO on the basis of the Integrated Model to Assess the Global Environment (IMAGE), developed by Netherlands Environmental Assessment Agency; [c] interpreted by the European Commission as the baseline scenario, i.e. the scenario characterized by policy inaction.

Table A1b: Projection of Forest Areas for Recreational Use or Conservation in Europe (1000 ha)

	Initial 2005	A1 2050	A2 2050	B1 2050	B2 2050	Initial 2005	A1 2050	A2 2050	B1 2050	B2 2050
N35-45	Forest areas designated for recreational use					Forest areas designated for conservation				
Greece	293.03	179.01	184.31	293.83	280.97	382.70	233.79	240.71	383.74	366.96
Italy	779.36	651.84	644.59	911.99	928.87	1,017.86	851.32	841.84	1,191.08	1,213.13
Portugal	295.45	169.47	169.82	254.13	256.40	385.87	221.33	221.79	331.90	334.86
Spain	1,399.16	941.28	934.80	1,358.05	1,377.12	1,827.33	1,229.32	1,220.87	1,773.64	1,798.54
Albania	62.01	40.56	65.20	71.71	77.43	80.99	52.97	85.15	93.65	101.12
Bosnia and Herzegovina	210.40	115.24	185.25	203.75	220.00	274.79	150.51	241.94	266.10	287.32
Bulgaria	283.11	178.01	286.14	314.72	339.81	369.75	232.48	373.71	411.03	443.80
Serbia and Montenegro	210.40	139.72	224.59	247.02	266.72	274.79	182.47	293.32	322.61	348.34
Turkey	794.67	530.17	852.24	937.35	1,012.09	1,037.85	692.42	1,113.04	1,224.20	1,321.81
Yugoslav	283.11	47.79	76.81	84.48	91.22	369.75	62.41	100.32	110.34	119.14
Total	**4,610.71**	**2,993.09**	**3,623.76**	**4,677.05**	**4,850.63**	**6,021.67**	**3,909.03**	**4,732.69**	**6,108.31**	**6,335.02**
N45-55	Forest areas designated for recreational use					Forest areas designated for conservation				
Austria	301.62	413.76	404.33	406.06	427.26	393.92	540.38	528.07	530.32	558.01
Belgium	52.09	41.08	42.59	54.48	65.77	68.03	53.65	55.63	71.16	85.90
France	1,214.77	1,178.86	1,253.96	1,568.23	1,712.41	1,586.51	1,539.61	1,637.69	2,048.13	2,236.44
Germany	865.04	784.82	786.89	991.56	1,095.97	1,129.75	1,024.99	1,027.69	1,294.99	1,431.36
Ireland	52.25	34.51	29.58	49.83	51.24	68.24	45.07	38.63	65.08	66.92
Luxembourg	6.79	6.28	6.13	8.07	7.34	8.87	8.20	8.00	10.54	9.59
Netherlands	28.51	11.80	32.84	25.97	32.25	37.23	15.41	42.89	33.92	42.12
Switzerland	95.36	155.01	149.41	165.01	165.64	124.54	202.44	195.13	215.51	216.33
Croatia	166.74	112.29	180.50	198.53	214.36	217.77	146.65	235.74	259.28	279.96
Czech Republic	206.81	139.08	223.57	245.90	265.51	270.10	181.65	291.99	321.15	346.76
Hungary	154.33	100.58	161.68	177.83	192.01	201.55	131.36	211.16	232.25	250.77
Poland	717.90	477.80	768.05	844.76	912.11	937.58	624.02	1,003.09	1,103.27	1,191.24
Romania	497.50	335.76	539.73	593.63	640.97	649.74	438.51	704.90	775.30	837.11
Slovakia	150.65	101.32	162.87	179.13	193.42	196.76	132.33	212.71	233.95	252.61
Slovenia	98.72	65.35	105.05	115.54	124.75	128.93	85.35	137.19	150.89	162.93
Total	**4,609.07**	**3,958.30**	**4,847.18**	**5,624.54**	**6,101.01**	**6,019.53**	**5,169.61**	**6,330.51**	**7,345.75**	**7,968.03**
N55-65	Forest areas designated for recreational use					Forest areas designated for conservation				
Denmark	39.05	32.30	52.88	33.90	65.53	51.00	42.18	69.06	44.28	85.58
United Kingdom	222.19	155.11	167.54	217.15	271.48	290.19	202.57	218.81	283.60	354.56
Estonia	178.38	118.30	190.17	209.16	225.84	232.97	154.51	248.36	273.17	294.95
Latvia	229.69	152.16	244.60	269.03	290.48	299.98	198.73	319.45	351.36	379.37
Lithuania	163.93	106.54	171.26	188.37	203.39	214.10	139.14	223.67	246.01	265.63
Total	**833.25**	**564.41**	**826.45**	**917.61**	**1,056.72**	**1,088.24**	**737.13**	**1,079.36**	**1,198.41**	**1,380.09**
N65-71	Forest areas designated for recreational use					Forest areas designated for conservation				
Finland	1,757.25	1,423.29	1,405.73	1,289.95	1,333.84	2,295.00	1,858.84	1,835.91	1,684.70	1,742.02
Iceland	3.59	2.31	2.26	2.21	2.18	4.69	3.02	2.95	2.88	2.85
Norway	733.12	505.93	490.22	401.48	449.93	957.47	660.75	640.23	524.34	587.62
Sweden	2,149.94	1,773.15	1,733.67	2,021.52	1,773.21	2,807.86	2,315.76	2,264.20	2,640.15	2,315.84
Total	**4,643.90**	**3,704.67**	**3,631.88**	**3,715.15**	**3,559.17**	**6,065.02**	**4,838.36**	**4,743.29**	**4,852.06**	**4,648.34**

Note: the projection of forest areas for 2050 is computed based on the ATEAM projection of total forest areas changed under IPCC scenarios, assuming constant proportions of total forest areas designated for recreational use (7.81%) or conservation use (10.2%), which are the average of the real data of the designated forest composition recorded by FAO/FRA 2005.

Table A2a. Projections of wood pulp (Estimates in Mt/yr)

Latitude	Country	2005[a]	2050 A1FI[b]	2050 A2[b, c]	2050 B1[b]	2050 B2[b]
35 to 45	Greece	0.00	0.32	0.33	0.52	0.50
	Italy	0.52	0.26	0.26	0.33	0.37
	Portugal	1.93	1.52	1.59	1.97	1.99
	Spain	1.97	1.33	1.32	1.72	1.94
	Albania	0.00	0.00	0.00	0.00	0.00
	Bosnia and Herzegovina	0.02	0.01	0.02	0.02	0.02
	Bulgaria	0.14	0.08	0.14	0.14	0.15
	Serbia and Montenegro	0.02	0.02	0.03	0.03	0.03
	Turkey	0.23	0.15	0.24	0.24	0.27
	TFRY Macedonia	0.00	0.00	0.00	0.00	0.00
	Regional Total	4.82	3.68	3.92	4.97	5.27
45 to 55	Austria	1.93	3.25	3.13	2.24	2.98
	Belgium	0.51	0.42	0.44	0.46	0.56
	France	2.50	1.95	2.10	2.26	2.47
	Germany	2.88	2.25	2.25	2.23	2.63
	Ireland	0.00	0.00	0.00	0.00	0.00
	Luxembourg	0.00	0.00	0.00	0.00	0.00
	Netherlands	0.12	0.04	0.16	0.09	0.11
	Switzerland	0.26	0.47	0.45	0.46	0.41
	Croatia	0.10	0.08	0.13	0.08	0.12
	Czech Republic	0.75	0.61	0.99	0.61	0.91
	Hungary	0.00	0.00	0.00	0.00	0.00
	Poland	1.05	0.84	1.36	0.84	1.26
	Romania	0.16	0.13	0.21	0.13	0.20
	Slovakia	0.61	0.49	0.80	0.49	0.74
	Slovenia	0.15	0.12	0.20	0.12	0.18
	Regional Total	10.88	10.53	12.01	9.89	12.39
55 to 65	Denmark	0.00	0.00	0.00	0.00	0.00
	United Kingdom	0.34	0.27	0.32	0.28	0.37
	Estonia	0.07	0.05	0.10	0.06	0.08
	Latvia	0.00	0.00	0.00	0.00	0.00
	Lithuania	0.00	0.00	0.00	0.00	0.00
	Regional Total	0.41	0.33	0.42	0.33	0.45
65 to 71	Finland	11.13	10.93	10.53	8.92	9.74
	Iceland	0.00	0.00	0.00	0.00	0.00
	Norway	2.46	1.51	1.22	1.11	1.28
	Sweden	12.11	12.70	12.25	12.49	11.58
	Regional Total	25.70	25.14	24.00	22.51	22.60

Notes: [a] data from FAO; [b] projections by ATEAM and CLIBIO on the basis of the Integrated Model to Assess the Global Environment (IMAGE), developed by Netherlands Environmental Assessment Agency; [c] interpreted by the European Commission as the baseline scenario, i.e. the scenario characterized by policy inaction.

Table A2b. Projections of industrial roundwood (Estimates in million m3/year)

Latitude	Country	2005[a]	2050 A1FI [b]	2050 A2[b, c]	2050 B1 [b]	2050 B2 [b]
35 to 45	Greece	0.52	0.32	0.33	0.52	0.50
	Italy	2.69	1.35	1.33	1.74	1.92
	Portugal	10.51	8.27	8.66	10.71	10.81
	Spain	13.35	8.98	8.92	11.65	13.12
	Albania	0.08	0.05	0.08	0.08	0.09
	Bosnia and Herzegovina	2.44	1.33	2.17	2.15	2.42
	Bulgaria	3.18	1.99	3.25	3.22	3.61
	Serbia and Montenegro	1.32	0.87	1.42	1.40	1.58
	Turkey	11.20	7.42	12.12	12.01	13.50
	TFRY Macedonia	0.00	0.00	0.00	0.00	0.00
	Regional Total	45.28	30.57	38.27	43.49	47.55
45 to 55	Austria	12.79	21.50	20.72	14.85	19.74
	Belgium	4.30	3.55	3.69	3.88	4.75
	France	31.62	24.64	26.50	28.53	31.17
	Germany	50.91	39.82	39.73	39.44	46.58
	Ireland	2.63	1.43	1.19	1.45	1.84
	Luxembourg	0.26	0.24	0.24	0.31	0.29
	Netherlands	0.82	0.31	1.13	0.62	0.77
	Switzerland	3.98	7.09	6.82	7.01	6.18
	Croatia	3.11	2.51	4.08	2.51	3.77
	Czech Republic	14.29	11.51	18.70	11.52	17.30
	Hungary	2.80	2.19	3.56	2.19	3.29
	Poland	28.53	22.75	36.95	22.78	34.19
	Romania	11.54	9.33	15.16	9.34	14.03
	Slovakia	9.01	7.26	11.79	7.26	10.91
	Slovenia	1.79	1.42	2.31	1.42	2.13
	Regional Total	176.58	154.13	190.23	151.69	194.81
55 to 65	Denmark	1.03	0.92	1.88	0.72	1.26
	United Kingdom	8.27	6.67	7.73	6.72	8.88
	Estonia	5.50	4.08	7.60	4.37	6.57
	Latvia	11.89	8.81	16.41	11.44	12.10
	Lithuania	4.92	3.57	6.65	4.64	4.90
	Regional Total	31.60	24.04	40.26	27.89	33.71
65 to 71	Finland	47.12	46.25	44.56	37.74	41.22
	Iceland	0.00	0.00	0.00	0.00	0.00
	Norway	8.49	5.23	4.21	3.82	4.42
	Sweden	91.70	96.18	92.79	94.57	87.69
	Regional Total	147.31	147.66	141.56	136.13	133.33

Note: [a] data from FAO; [b] projections by ATEAM and CLIBIO on the basis of the Integrated Model to Assess the Global Environment (IMAGE), developed by Netherlands Environmental Assessment Agency; [c] interpreted by the European Commission as the baseline scenario, i.e. the scenario characterized by policy inaction.

Table A2c. Projections of recovered paper (Estimates in Mt/yr)

Latitude	Country	2005[a]	2050 A1FI[b]	2050 A2[b, c]	2050 B1[b]	2050 B2[b]
35 to 45	Greece	0.35	0.32	0.33	0.52	0.50
	Italy	5.49	2.76	2.72	3.55	3.92
	Portugal	0.60	0.47	0.49	0.61	0.61
	Spain	4.32	2.91	2.89	3.77	4.25
	Albania	0.00	0.00	0.00	0.00	0.00
	Bosnia and Herzegovina	0.00	0.00	0.00	0.00	0.00
	Bulgaria	0.08	0.05	0.08	0.08	0.09
	Serbia and Montenegro	0.00	0.00	0.00	0.00	0.00
	Turkey	1.02	0.00	0.00	0.00	0.00
	TFRY Macedonia	0.00	0.67	1.10	1.09	1.22
	Regional Total	11.85	7.18	7.61	9.62	10.60
45 to 55	Austria	1.42	7.18	7.61	9.62	10.60
	Belgium	2.14	2.39	2.30	1.65	2.19
	France	5.95	1.77	1.83	1.93	2.36
	Germany	14.41	4.64	4.99	5.37	5.87
	Ireland	0.44	11.27	11.25	11.17	13.19
	Luxembourg	0.06	0.24	0.20	0.24	0.31
	Netherlands	2.46	0.06	0.06	0.07	0.07
	Switzerland	1.24	0.93	3.38	1.87	2.32
	Croatia	0.00	2.42	2.36	1.46	2.04
	Czech Republic	0.48	0.39	0.63	0.39	0.58
	Hungary	0.37	0.29	0.47	0.29	0.43
	Poland	1.20	0.96	1.55	0.96	1.44
	Romania	0.30	0.24	0.39	0.24	0.36
	Slovakia	0.21	0.17	0.28	0.17	0.26
	Slovenia	0.00	0.00	0.00	0.00	0.00
	Regional Total	30.69	25.76	29.68	25.80	31.42
55 to 65	Denmark	0.44	0.39	0.80	0.31	0.53
	United Kingdom	7.76	6.25	7.25	6.30	8.33
	Estonia	0.05	0.04	0.07	0.04	0.06
	Latvia	0.06	0.04	0.08	0.06	0.06
	Lithuania	0.08	0.06	0.11	0.07	0.08
	Regional Total	8.38	6.78	8.31	6.78	9.06
65 to 71	Finland	0.60	0.59	0.57	0.48	0.52
	Iceland	0.01	0.01	0.01	0.01	0.01
	Norway	0.44	0.27	0.22	0.20	0.23
	Sweden	1.57	1.64	1.59	1.62	1.50
	Regional Total	2.62	2.51	2.38	2.30	2.26

Notes: [a] data from FAO; [b] projections by ATEAM and CLIBIO on the basis of the Integrated Model to Assess the Global Environment (IMAGE), developed by Netherlands Environmental Assessment Agency; [c] interpreted by the European Commission as the baseline scenario, i.e. the scenario characterized by policy inaction.

Table A2d. Projections of sawnwood (Estimates in Mm3/yr)

Latitude	Country	2005[a]	2050 A1FI [b]	2050 A2[b, c]	2050 B1 [b]	2050 B2 [b]
35 to 45	Greece	0.19	0.32	0.33	0.52	0.50
	Italy	1.59	0.80	0.79	1.03	1.14
	Portugal	1.01	0.80	0.83	1.03	1.04
	Spain	3.66	2.46	2.44	3.19	3.60
	Albania	0.10	0.06	0.10	0.10	0.11
	Bosnia and Herzegovina	1.32	0.72	1.17	1.16	1.30
	Bulgaria	0.57	0.36	0.58	0.58	0.65
	Serbia and Montenegro	0.50	0.33	0.54	0.53	0.60
	Turkey	6.45	4.27	6.97	6.91	7.77
	TFRY Macedonia	0.00	0.00	0.00	0.00	0.00
	Regional Total	15.38	10.11	13.75	15.05	16.70
45 to 55	Austria	11.07	18.62	17.94	12.86	17.10
	Belgium	1.29	1.06	1.10	1.16	1.42
	France	9.95	7.75	8.34	8.98	9.81
	Germany	22.12	17.30	17.26	17.14	20.24
	Ireland	0.89	0.49	0.41	0.49	0.62
	Luxembourg	0.13	0.12	0.12	0.16	0.14
	Netherlands	0.28	0.11	0.38	0.21	0.26
	Switzerland	1.59	2.84	2.73	2.80	2.47
	Croatia	0.62	0.50	0.82	0.50	0.76
	Czech Republic	4.00	3.23	5.24	3.23	4.85
	Hungary	0.22	0.17	0.27	0.17	0.25
	Poland	3.93	3.13	5.09	3.14	4.71
	Romania	4.32	3.49	5.68	3.50	5.25
	Slovakia	2.62	2.11	3.43	2.11	3.17
	Slovenia	0.46	0.37	0.59	0.37	0.55
	Regional Total	63.04	60.93	68.81	56.45	71.07
55 to 65	Denmark	0.20	0.18	0.36	0.14	0.24
	United Kingdom	2.86	2.31	2.68	2.33	3.07
	Estonia	2.20	1.63	3.04	1.75	2.63
	Latvia	4.23	3.13	5.83	4.07	4.30
	Lithuania	1.50	1.09	2.03	1.42	1.50
	Regional Total	10.98	8.33	13.93	9.69	11.74
65 to 71	Finland	12.27	12.04	11.60	9.83	10.73
	Iceland	0.00	0.00	0.00	0.00	0.00
	Norway	2.33	1.44	1.15	1.05	1.21
	Sweden	18.00	18.88	18.21	18.56	17.21
	Regional Total	32.60	32.36	30.97	29.44	29.16

Notes: [a] data from FAO; [b] projections by ATEAM and CLIBIO on the basis of the Integrated Model to Assess the Global Environment (IMAGE), developed by Netherlands Environmental Assessment Agency; [c] interpreted by the European Commission as the baseline scenario, i.e. the scenario characterized by policy inaction.

Table A2e. Projections of wood-based panels (Estimates in Mm3/yr)

Latitude	Country	2005[a]	2050 A1FI [b]	2050 A2[b, c]	2050 B1 [b]	2050 B2 [b]
35 to 45	Greece	0.87	0.32	0.33	0.52	0.50
	Italy	5.61	2.82	2.79	3.63	4.01
	Portugal	1.31	1.03	1.08	1.33	1.34
	Spain	4.84	3.26	3.24	4.23	4.76
	Albania	0.04	0.02	0.04	0.04	0.04
	Bosnia and Herzegovina	0.00	0.00	0.00	0.00	0.00
	Bulgaria	0.35	0.22	0.35	0.35	0.39
	Serbia and Montenegro	0.07	0.05	0.08	0.07	0.08
	Turkey	4.77	3.16	5.16	5.12	5.75
	TFRY Macedonia	0.00	0.00	0.00	0.00	0.00
	Regional Total	17.86	10.87	13.06	15.29	16.88
45 to 55	Austria	3.45	5.81	5.60	4.01	5.33
	Belgium	2.80	2.32	2.40	2.53	3.10
	France	6.40	4.99	5.36	5.77	6.31
	Germany	16.98	13.28	13.25	13.15	15.54
	Ireland	0.88	0.48	0.40	0.48	0.61
	Luxembourg	0.45	0.42	0.41	0.53	0.49
	Netherlands	0.01	0.00	0.02	0.01	0.01
	Switzerland	0.97	1.72	1.65	1.70	1.50
	Croatia	0.13	0.10	0.17	0.10	0.16
	Czech Republic	1.49	1.20	1.95	1.20	1.81
	Hungary	0.67	0.53	0.85	0.53	0.79
	Poland	6.74	5.37	8.73	5.38	8.07
	Romania	1.01	0.82	1.33	0.82	1.23
	Slovakia	0.61	0.49	0.79	0.49	0.73
	Slovenia	0.41	0.33	0.53	0.33	0.49
	Regional Total	42.58	37.52	42.91	36.71	45.67
55 to 65	Denmark	0.35	0.31	0.63	0.24	0.42
	United Kingdom	3.40	2.74	3.18	2.76	3.65
	Estonia	0.41	0.30	0.57	0.33	0.49
	Latvia	0.43	0.32	0.59	0.41	0.43
	Lithuania	0.40	0.29	0.54	0.38	0.40
	Regional Total	4.98	3.96	5.50	4.12	5.39
65 to 71	Finland	1.99	1.95	1.88	1.59	1.74
	Iceland	0.00	0.00	0.00	0.00	0.00
	Norway	0.58	0.36	0.29	0.26	0.30
	Sweden	0.75	0.78	0.76	0.77	0.71
	Regional Total	3.31	3.09	2.92	2.62	2.75

Notes: [a] data from FAO; [b] projections by ATEAM and CLIBIO on the basis of the Integrated Model to Assess the Global Environment (IMAGE), developed by Netherlands Environmental Assessment Agency; [c] interpreted by the European Commission as the baseline scenario, i.e. the scenario characterized by policy inaction.

Table A2f. Projections of paper and paperboard (Estimates in Mt/yr)

Latitude	Country	2005[a]	2050 A1FI[b]	2050 A2[b, c]	2050 B1[b]	2050 B2[b]
35 to 45	Greece	0.53	0.32	0.33	0.52	0.50
	Italy	10.00	5.03	4.96	6.46	7.14
	Portugal	1.58	1.24	1.30	1.61	1.62
	Spain	5.70	3.83	3.81	4.97	5.60
	Albania	0.00	0.00	0.00	0.00	0.00
	Bosnia and Herzegovina	0.08	0.04	0.07	0.07	0.08
	Bulgaria	0.33	0.20	0.33	0.33	0.37
	Serbia and Montenegro	0.23	0.15	0.25	0.24	0.27
	Turkey	1.15	0.76	1.25	1.24	1.39
	TFRY Macedonia	0.00	0.00	0.00	0.00	0.00
	Regional Total	19.60	11.58	12.30	15.45	16.98
45 to 55	Austria	4.95	8.32	8.02	5.75	7.64
	Belgium	1.90	1.57	1.63	1.71	2.10
	France	10.33	8.05	8.66	9.32	10.19
	Germany	21.68	16.96	16.92	16.80	19.84
	Ireland	0.05	0.02	0.02	0.02	0.03
	Luxembourg	0.00	0.00	0.00	0.00	0.00
	Netherlands	3.47	1.32	4.77	2.63	3.27
	Switzerland	1.75	3.12	3.00	3.08	2.72
	Croatia	0.59	0.48	0.78	0.48	0.72
	Czech Republic	0.97	0.78	1.27	0.78	1.17
	Hungary	0.57	0.45	0.72	0.45	0.67
	Poland	2.73	2.18	3.54	2.18	3.27
	Romania	0.37	0.30	0.49	0.30	0.45
	Slovakia	0.86	0.69	1.12	0.69	1.04
	Slovenia	0.56	0.44	0.72	0.44	0.66
	Regional Total	50.22	44.24	50.93	44.20	53.11
55 to 65	Denmark	0.42	0.38	0.77	0.30	0.52
	United Kingdom	6.24	5.03	5.83	5.07	6.70
	Estonia	0.07	0.05	0.09	0.05	0.08
	Latvia	0.04	0.03	0.05	0.04	0.04
	Lithuania	0.11	0.08	0.15	0.11	0.11
	Regional Total	6.88	5.57	6.90	5.56	7.45
65 to 71	Finland	12.39	12.16	11.72	9.93	10.84
	Iceland	0.00	0.00	0.00	0.00	0.00
	Norway	2.22	1.37	1.10	1.00	1.16
	Sweden	11.74	12.31	11.87	12.10	11.22
	Regional Total	26.35	25.84	24.70	23.03	23.22

Notes: [a] data from FAO; [b] projections by ATEAM and CLIBIO on the basis of the Integrated Model to Assess the Global Environment (IMAGE), developed by Netherlands Environmental Assessment Agency; [c] interpreted by the European Commission as the baseline scenario, i.e. the scenario characterized by policy inaction.

Table A2g. Projection of woodfuel (Estimates in Mm3/yr)

Latitude	Country	2005[a]	2050 A1FI [b]	2050 A2[b, c]	2050 B1 [b]	2050 B2 [b]
35 to 45	Greece	1.00	0.32	0.33	0.52	0.50
	Italy	5.36	2.69	2.66	3.46	3.83
	Portugal	0.60	0.47	0.49	0.61	0.62
	Spain	2.18	1.47	1.46	1.90	2.14
	Albania	0.22	0.14	0.23	0.23	0.26
	Bosnia and Herzegovina	1.36	0.74	1.21	1.20	1.35
	Bulgaria	2.68	1.67	2.73	2.71	3.04
	Serbia and Montenegro	1.85	1.22	2.00	1.98	2.22
	Turkey	4.98	3.30	5.39	5.34	6.00
	TFRY Macedonia	0.00	0.00	0.00	0.00	0.00
	Regional Total	20.24	12.03	16.50	17.96	19.96
45 to 55	Austria	3.69	6.20	5.97	4.28	5.69
	Belgium	0.65	0.54	0.56	0.59	0.72
	France	2.80	2.18	2.35	2.53	2.76
	Germany	6.04	4.73	4.71	4.68	5.53
	Ireland	0.02	0.01	0.01	0.01	0.01
	Luxembourg	0.01	0.01	0.01	0.02	0.01
	Netherlands	0.29	0.11	0.40	0.22	0.27
	Switzerland	1.07	1.90	1.83	1.88	1.65
	Croatia	0.91	0.61	0.98	1.08	1.17
	Czech Republic	1.23	0.99	1.60	0.99	1.48
	Hungary	3.14	2.45	3.98	2.45	3.68
	Poland	3.41	2.72	4.42	2.72	4.09
	Romania	2.96	2.39	3.89	2.40	3.60
	Slovakia	0.30	0.24	0.39	0.24	0.36
	Slovenia	0.94	0.75	1.22	0.75	1.12
	Regional Total	26.50	25.07	31.09	24.07	31.03
55 to 65	Denmark	1.26	1.13	2.31	0.89	1.54
	United Kingdom	0.32	0.26	0.30	0.26	0.34
	Estonia	1.30	0.96	1.80	1.03	1.55
	Latvia	0.95	0.70	1.31	0.91	0.97
	Lithuania	1.13	0.82	1.53	1.07	1.13
	Regional Total	4.96	3.87	7.24	4.16	5.53
65 to 71	Finland	4.48	4.40	4.24	3.59	3.92
	Iceland	0.00	0.00	0.00	0.00	0.00
	Norway	1.18	0.72	0.58	0.53	0.61
	Sweden	7.00	7.34	7.08	7.22	6.69
	Regional Total	12.66	12.47	11.91	11.34	11.23

Notes: [a] data from FAO; [b] projections by ATEAM and CLIBIO on the basis of the Integrated Model to Assess the Global Environment (IMAGE), developed by Netherlands Environmental Assessment Agency; [c] interpreted by the European Commission as the baseline scenario, i.e. the scenario characterized by policy inaction.

Table A3. Projection of carbon stock in European forests (Estimates in Mt/year)

Latitude	Country	1990[a]	2005[b]	2050[d] A1FI	2050[d] A2	2050[d] B1	2050[d] B2
35 to 45	Greece	293.23	305.53	190.46	201.11	368.57	319.44
	Italy	1,315.59	1,389.67	1,186.02	1,200.24	1,826.60	1,770.73
	Portugal	161.08	170.08	99.55	101.92	218.21	169.31
	Spain	987.42	1,076.28	738.83	758.43	1,224.48	1,162.31
	Albania	62.62	64.66	43.15	71.14	89.95	88.03
	Bosnia and Herzegovina	177.93	177.93	122.61	202.14	255.58	250.11
	Bulgaria	274.83	295.19	189.39	312.23	394.78	386.33
	Serbia and Montenegro	215.71	219.38	148.65	245.07	309.86	303.23
	Turkey	818.55	828.57	564.07	929.94	1,175.81	1,150.64
	TFRY Macedonia	73.78	73.78	50.84	83.82	105.98	103.71
	Regional Total	4,380.75	4,601.05	3,333.57	4,106.03	5,969.82	5,703.84
45 to 55	Austria	937.51	943.37	1,454.04	1,440.26	1,549.25	1,562.36
	Belgium	72.87	72.87	64.56	67.19	97.03	103.55
	France	1,702.22	1,724.73	1,880.61	2,135.35	3,134.30	3,099.40
	Germany	1,257.57	1,257.57	1,281.98	1,395.33	2,233.45	2,130.37
	Ireland	71.30	78.33	58.13	51.71	99.80	94.39
	Luxembourg	23.50	23.50	24.40	24.53	31.68	27.03
	Netherlands	52.10	52.82	24.57	69.80	61.58	71.22
	Switzerland	294.63	300.04	547.99	540.40	653.70	620.48
	Croatia	575.06	576.68	436.35	722.68	779.21	788.89
	Czech Republic	712.27	715.24	540.47	895.12	965.14	977.12
	Hungary	515.09	533.73	390.85	647.32	697.96	706.63
	Poland	2,446.89	2,482.82	1,856.69	3,075.03	3,315.58	3,356.76
	Romania	1,719.50	1,720.58	1,304.75	2,160.91	2,329.95	2,358.88
	Slovakia	518.87	521.03	393.72	652.07	703.08	711.81
	Slovenia	334.66	341.41	253.94	420.57	453.47	459.10
	Regional Total	11,234.0	11,344.7	10,513.0	14,298.2	17,105.1	17,068.0
55 to 65	Denmark	60.92	62.68	53.44	91.68	71.13	121.77
	United Kingdom	409.39	417.01	300.10	334.64	498.37	568.02
	Estonia	304.98	310.55	212.33	354.77	459.44	446.08
	Latvia	392.27	399.88	273.10	456.31	590.95	573.76
	Lithuania	274.66	285.40	191.22	319.50	413.77	401.73
	Regional Total	1,442.21	1,475.52	1,030.20	1,556.89	2,033.65	2,111.36
65 to 71	Finland	1,040.16	1,041.32	869.50	903.69	1,219.41	991.76
	Norway	786.34	793.61	564.61	560.76	511.91	535.89
	Sweden	1,770.79	1,774.27	1,508.58	1,459.27	2,421.32	1,676.58
	Regional Total	3,597.29	3,609.20	2,942.69	2,923.71	4,152.64	3,204.23

Notes: [a] data from Karjalainen et al. (2003) and Advanced Terrestrial Ecosystem Analysis and Modelling (ATEAM), PIK; [b] EIBURS projections ; [c] projections by Karjalainen et al. (2003); [d] projections by ATEAM and EIBURS need to add the Finland study.

Table A4a. Economic value of wood pulp (Estimates in \$/ha/year, \$2005)

Latitude	Country	2005[a]	2050 A1FI [b]	2050 A2[b, c]	2050 B1 [b]	2050 B2 [b]
35 to 45	Greece	n.a.	n.a.	n.a.	n.a.	n.a.
	Italy	1.56	0.94	0.94	0.86	0.94
	Portugal	102.35	140.45	146.85	121.32	121.40
	Spain	29.49	29.48	29.48	26.52	29.45
	Albania	n.s.	n.s.	n.s.	n.s.	n.s.
	Bosnia and Herzegovina	n.s.	n.s.	n.s.	n.s.	n.s.
	Bulgaria	6.88	8.43	8.31	5.93	7.50
	Serbia and Montenegro	0.09	0.09	0.09	0.08	0.08
	Turkey	0.02	0.02	0.02	0.02	0.02
	TFRY Macedonia	n.s.	n.s.	n.s.	n.s.	n.s.
	Regional Average	16.25	19.66	16.54	16.01	16.56
45 to 55	Austria	33.80	41.43	40.86	29.16	36.85
	Belgium	590.07	618.64	412.76	339.12	344.33
	France	15.63	12.55	12.69	10.93	10.93
	Germany	38.92	33.55	33.39	26.31	28.11
	Ireland	n.s.	n.s.	n.s.	n.s.	n.s.
	Luxembourg	n.s.	n.s.	n.s.	n.s.	n.s.
	Netherlands	865.81	794.10	1,031.84	721.28	721.20
	Switzerland	70.23	77.01	76.84	71.49	62.80
	Croatia	6.24	5.84	6.07	5.05	5.12
	Czech Republic	65.77	61.57	63.95	53.22	53.88
	Hungary	n.s.	n.s.	n.s.	n.s.	n.s.
	Poland	2.28	2.13	2.21	1.84	1.86
	Romania	0.95	0.89	0.93	0.77	0.78
	Slovakia	23.77	29.13	28.73	20.50	25.91
	Slovenia	16.98	15.89	16.51	13.74	13.91
	Regional Average	31.89	32.16	34.38	24.13	26.27
55 to 65	Denmark	n.s.	n.s.	n.s.	n.s.	n.s.
	United Kingdom	0.96	1.11	1.19	0.80	0.85
	Estonia	n.a.	n.a.	n.a.	0.00	n.a.
	Latvia	n.s.	n.s.	n.s.	0.00	n.s.
	Lithuania	n.s.	n.s.	n.s.	n.s.	n.s.
	Regional Average	0.29	0.43	0.28	0.22	0.26
65 to 71	Finland	45.60	55.26	53.91	49.75	52.56
	Iceland	n.s.	n.s.	n.s.	n.s.	n.s.
	Norway	39.79	35.52	29.48	32.70	33.75
	Sweden	68.66	87.32	86.15	75.30	79.60
	Regional Average	55.32	90.20	87.33	81.53	84.41

Notes: [a] data from FAO; [b] EIBURS projections; [c] interpreted by the European Commission as the baseline scenario, i.e. the scenario characterized by policy inaction; n.a. not available; n.s. not significant

Table A4b. Economic value of industrial roundwood (Estimates in $/ha/year, $2005)

Latitude	Country	2005[a]	2050 A1FI[b]	2050 A2[b, c]	2050 B1[b]	2050 B2[b]
35 to 45	Greece	0.01	0.02	0.02	0.02	0.02
	Italy	0.67	0.37	0.37	0.34	0.36
	Portugal	22.63	37.34	39.05	32.26	32.28
	Spain	0.78	0.77	0.77	0.70	0.77
	Albania	0.18	0.23	0.15	0.18	0.17
	Bosnia and Herzegovina	3.92	9.29	5.57	3.63	4.47
	Bulgaria	5.16	9.66	5.79	3.78	4.65
	Serbia and Montenegro	2.84	3.34	2.17	2.84	2.62
	Turkey	0.28	0.35	0.22	0.26	0.25
	TFRY Macedonia	n.s.	n.s.	n.s.	n.s.	n.s.
	Regional Average	2.48	3.59	3.03	2.64	2.72
45 to 55	Austria	20.59	18.81	18.55	13.24	16.73
	Belgium	138.03	175.94	117.39	96.44	97.93
	France	16.76	11.77	11.90	10.24	10.25
	Germany	40.66	34.32	34.15	26.91	28.75
	Ireland	19.65	17.61	17.13	12.37	15.22
	Luxembourg	193.71	195.07	194.93	194.38	194.58
	Netherlands	61.83	103.89	135.00	94.37	94.36
	Switzerland	95.31	62.05	61.91	57.60	50.59
	Croatia	17.57	22.89	17.72	15.64	16.03
	Czech Republic	67.52	88.29	68.35	60.32	61.82
	Hungary	29.62	36.67	28.39	25.06	25.68
	Poland	4.56	5.87	4.54	4.01	4.11
	Romania	2.27	2.98	2.31	2.04	2.09
	Slovakia	49.69	94.39	56.58	36.87	45.41
	Slovenia	20.12	25.30	19.58	17.28	17.71
	Regional Average	25.48	25.78	22.44	18.33	19.20
55 to 65	Denmark	87.92	100.33	148.98	89.39	80.45
	United Kingdom	14.66	23.62	21.34	14.32	15.13
	Estonia	41.71	67.97	68.94	34.21	49.28
	Latvia	62.65	101.85	103.30	51.26	73.84
	Lithuania	27.16	44.20	44.82	22.24	32.04
	Regional Average	39.57	62.28	69.58	34.08	45.87
65 to 71	Finland	2.86	4.65	4.54	4.19	4.42
	Iceland	n.s.	n.s.	n.s.	n.s.	n.s.
	Norway	3.05	4.79	3.98	4.41	4.55
	Sweden	6.33	10.24	10.10	8.83	9.33
	Regional Average	4.49	7.34	7.11	6.73	6.88

Notes: [a] data from FAO; [b] EIBURS projections; [c] interpreted by the European Commission as the baseline scenario, i.e. the scenario characterized by policy inaction; n.a. not available; n.s. not significant

Table A4c. Economic value of recovered paper (Estimates in $/ha/year, $2005)

Latitude	Country	2005[a]	2050 A1FI [b]	2050 A2[b, c]	2050 B1 [b]	2050 B2 [b]
35 to 45	Greece	3.60	3.60	3.60	3.60	3.60
	Italy	8.27	4.97	4.96	4.57	4.96
	Portugal	7.29	1n.s.	10.46	8.64	8.64
	Spain	3.40	3.40	3.40	3.06	3.40
	Albania	n.s.	n.s.	n.s.	n.s.	n.s.
	Bosnia and Herzegovina	n.s.	n.s.	n.s.	n.s.	n.s.
	Bulgaria	0.02	0.03	0.03	0.02	0.02
	Serbia and Montenegro	n.s.	n.s.	n.s.	n.s.	n.s.
	Turkey	0.03	0.03	0.03	0.03	0.03
	TFRY Macedonia	n.s.	n.a.	n.a.	n.a.	n.a.
	Regional Average	3.15	2.98	2.48	2.52	2.61
45 to 55	Austria	7.40	9.07	8.94	6.38	8.07
	Belgium	358.45	375.81	250.74	206.01	209.17
	France	12.94	10.39	10.51	9.05	9.05
	Germany	31.41	27.08	26.95	21.23	22.69
	Ireland	83.27	68.56	66.68	48.15	59.28
	Luxembourg	50.28	50.38	50.35	50.20	50.26
	Netherlands	905.42	830.43	1,079.05	754.28	754.20
	Switzerland	36.79	40.34	40.26	37.45	32.90
	Croatia	n.a.	n.a.	n.a.	n.a.	n.a.
	Czech Republic	7.52	7.04	7.32	6.09	6.17
	Hungary	3.38	3.16	3.29	2.73	2.77
	Poland	3.06	2.86	2.98	2.48	2.51
	Romania	0.09	0.08	0.08	0.07	0.07
	Slovakia	1.88	2.30	2.27	1.62	2.05
	Slovenia	n.s.	n.s.	n.s.	n.s.	n.s.
	Regional Average	22.38	20.64	25.56	17.05	18.68
55 to 65	Denmark	108.69	117.50	146.88	88.13	79.31
	United Kingdom	177.73	205.26	220.34	147.77	156.21
	Estonia	2.02	2.26	2.62	1.66	1.63
	Latvia	1.02	1.14	1.32	0.84	0.82
	Lithuania	0.61	0.68	0.79	0.50	0.49
	Regional Average	53.32	87.10	65.70	45.87	54.27
65 to 71	Finland	1.10	1.34	1.30	1.20	1.27
	Iceland	6.87	7.73	7.28	6.89	7.24
	Norway	2.76	2.47	2.05	2.27	2.34
	Sweden	1.28	1.63	1.60	1.40	1.48
	Regional Average	1.45	2.28	2.15	1.97	2.11

Notes: [a] data from FAO; [b] EIBURS projections; [c] interpreted by the European Commission as the baseline scenario, i.e. the scenario characterized by policy inaction; n.a. not available; n.s. not significant

Table A4d. Economic value of sawnwood (Estimates in $/ha/year, $2005)

Latitude	Country	2005[a]	2050 A1FI [b]	2050 A2[b, c]	2050 B1 [b]	2050 B2 [b]
35 to 45	Greece	1.81	1.81	1.81	1.81	1.81
	Italy	12.62	7.58	7.58	6.97	7.56
	Portugal	19.58	26.88	28.10	23.22	23.23
	Spain	2.76	2.76	2.76	2.49	2.76
	Albania	5.42	5.38	5.47	4.93	5.13
	Bosnia and Herzegovina	64.75	79.37	78.26	55.85	70.59
	Bulgaria	9.93	12.17	12.00	8.57	10.83
	Serbia and Montenegro	16.15	16.04	16.29	14.69	15.28
	Turkey	1.41	1.40	1.42	1.28	1.33
	TFRY Macedonia	n.s.	n.s.	n.s.	n.s.	n.s.
	Regional Average	8.40	11.50	9.41	7.39	8.19
45 to 55	Austria	384.74	471.59	465.02	331.85	419.42
	Belgium	625.39	655.66	437.47	359.42	364.94
	France	24.70	19.83	20.05	17.26	17.27
	Germany	145.36	125.32	124.71	98.25	104.99
	Ireland	101.69	83.73	81.44	58.80	72.39
	Luxembourg	128.85	129.12	129.03	128.67	128.80
	Netherlands	545.68	500.48	650.32	454.59	454.54
	Switzerland	37.06	40.63	40.55	37.72	33.13
	Croatia	71.22	66.67	69.25	57.63	58.35
	Czech Republic	124.31	116.37	120.88	100.59	101.85
	Hungary	34.17	31.99	33.23	27.65	28.00
	Poland	19.21	17.98	18.68	15.54	15.74
	Romania	79.43	74.35	77.23	64.27	65.07
	Slovakia	130.64	160.13	157.90	112.68	142.42
	Slovenia	64.45	60.33	62.67	52.15	52.81
	Regional Average	98.03	108.13	95.41	70.80	78.50
55 to 65	Denmark	109.74	118.64	148.29	88.98	80.08
	United Kingdom	38.67	44.66	47.94	32.15	33.99
	Estonia	106.66	119.24	138.18	87.58	85.79
	Latvia	189.99	212.41	246.14	156.01	152.81
	Lithuania	95.41	106.67	123.61	78.35	76.74
	Regional Average	109.43	173.30	189.22	94.61	126.62
65 to 71	Finland	71.84	87.07	84.94	78.39	82.81
	Iceland	n.s.	n.s.	n.s.	n.s.	n.s.
	Norway	10.06	8.98	7.45	8.27	8.53
	Sweden	103.43	131.53	129.78	113.43	119.92
	Regional Average	76.66	127.15	124.72	116.63	119.56

Notes: [a] data from FAO; [b] EIBURS projections; [c] interpreted by the European Commission as the baseline scenario, i.e. the scenario characterized by policy inaction; n.a. not available;
n.s. not significant

Table A4e. Economic value of woodbased panels (Estimates in $/ha/year, $2005)

Latitude	Country	2005[a]	2050 A1FI[b]	2050 A2[b, c]	2050 B1[b]	2050 B2[b]
35 to 45	Greece	15.89	15.89	15.89	15.89	15.89
	Italy	54.97	33.03	32.99	30.35	32.94
	Portugal	69.76	95.74	100.10	82.70	82.75
	Spain	37.17	37.16	37.16	33.42	37.12
	Albania	n.a.	n.a.	n.a.	n.a.	n.a.
	Bosnia and Herzegovina	7.07	6.74	6.89	6.10	7.71
	Bulgaria	25.85	31.68	31.24	22.29	28.18
	Serbia and Montenegro	4.45	4.42	4.48	4.04	4.21
	Turkey	13.62	13.53	13.74	12.39	12.89
	TFRY Macedonia	n.s.	n.s.	n.s.	n.s.	n.s.
	Regional Average	30.45	32.27	26.74	25.77	27.17
45 to 55	Austria	299.23	366.78	361.67	258.10	326.20
	Belgium	1,550.94	1,626.02	1,084.90	891.35	905.04
	France	68.95	55.37	55.99	48.19	48.22
	Germany	238.34	205.48	204.47	161.09	172.15
	Ireland	437.58	360.28	350.44	253.02	311.51
	Luxembourg	935.74	937.72	937.06	934.41	935.40
	Netherlands	369.83	339.19	440.75	308.09	308.06
	Switzerland	251.11	275.34	274.75	255.60	224.52
	Croatia	31.85	29.82	30.97	25.77	26.10
	Czech Republic	95.17	89.09	92.55	77.01	77.98
	Hungary	79.14	74.08	76.96	64.04	64.84
	Poland	83.11	77.80	80.81	67.25	68.09
	Romania	38.31	35.86	37.26	31.00	31.39
	Slovakia	62.83	77.01	75.94	54.19	68.49
	Slovenia	105.95	99.18	103.03	85.73	86.81
	Regional Average	143.31	147.03	123.51	99.57	107.17
55 to 65	Denmark	147.78	159.76	199.70	119.82	107.84
	United Kingdom	65.68	75.86	81.43	54.61	57.73
	Estonia	47.47	53.07	61.50	38.98	38.18
	Latvia	54.90	61.38	71.12	45.08	44.16
	Lithuania	24.63	27.54	31.91	20.23	19.81
	Regional Average	54.58	86.57	88.67	46.91	61.16
65 to 71	Finland	38.95	47.20	46.05	42.50	44.89
	Iceland	n.s.	n.s.	n.s.	n.s.	n.s.
	Norway	10.47	9.34	7.75	8.60	8.88
	Sweden	2.93	3.73	3.68	3.22	3.40
	Regional Average	17.75	28.88	28.02	23.69	26.73

Notes: [a] data from FAO; [b] EIBURS projections; [c] interpreted by the European Commission as the baseline scenario, i.e. the scenario characterized by policy inaction; n.a. not available; n.s. not significant

Table A4f. Economic value of paper and paperboard (Estimates in $/ha/year, $2005)

Latitude	Country	2005[a]	2050 A1FI [b]	2050 A2[b, c]	2050 B1 [b]	2050 B2 [b]
35 to 45	Greece	15.38	15.38	15.38	15.38	15.38
	Italy	245.11	147.28	147.11	135.33	146.86
	Portugal	269.59	369.96	386.82	319.58	319.77
	Spain	112.38	112.35	112.35	101.06	112.24
	Albania	n.s.	n.s.	n.s.	n.s.	n.s.
	Bosnia and Herzegovina	10.53	12.90	12.72	9.08	11.48
	Bulgaria	21.48	26.33	25.96	18.53	23.41
	Serbia and Montenegro	27.21	27.02	27.44	24.74	25.74
	Turkey	9.80	9.74	9.89	8.91	9.27
	TFRY Macedonia	n.s.	n.s.	n.s.	n.s.	n.s.
	Regional Average	98.44	97.00	80.62	79.47	83.24
45 to 55	Austria	784.74	961.90	948.49	676.88	855.48
	Belgium	3,941.70	4,132.52	2,757.27	2,265.35	2,300.15
	France	323.32	259.64	262.54	225.96	226.12
	Germany	1,007.18	868.32	864.06	680.74	727.46
	Ireland	113.45	93.40	90.85	65.60	80.76
	Luxembourg	n.s.	n.s.	n.s.	n.s.	n.s.
	Netherlands	7,362.62	6,752.78	8,774.50	6,133.54	6,132.89
	Switzerland	1,148.93	1,259.79	1,257.07	1,169.44	1,027.28
	Croatia	26.90	25.18	26.16	21.77	22.04
	Czech Republic	227.07	212.56	220.81	183.74	186.04
	Hungary	197.81	185.17	192.35	160.06	162.07
	Poland	118.69	111.11	115.42	96.04	97.25
	Romania	11.68	10.94	11.36	9.46	9.57
	Slovakia	262.27	321.48	317.00	226.22	285.91
	Slovenia	323.68	303.00	314.75	261.91	265.20
	Regional Average	495.49	487.19	472.55	352.27	380.78
55 to 65	Denmark	469.47	507.54	634.42	380.65	342.59
	United Kingdom	637.08	735.78	789.82	529.71	559.96
	Estonia	22.26	24.89	28.84	18.28	17.91
	Latvia	19.84	22.18	25.70	16.29	15.96
	Lithuania	19.06	21.31	24.69	15.65	15.33
	Regional Average	205.87	334.83	263.56	176.94	211.92
65 to 71	Finland	375.95	455.64	444.51	410.23	433.36
	Iceland	n.s.	n.s.	n.s.	n.s.	n.s.
	Norway	132.38	118.16	98.08	108.79	112.28
	Sweden	296.77	377.42	372.39	325.49	344.09
	Regional Average	300.55	493.29	480.48	437.27	461.16

Notes: [a] data from FAO; [b] EIBURS projections; [c] interpreted by the European Commission as the baseline scenario, i.e. the scenario characterized by policy inaction; n.a. not available; n.s. not significant

Table A4g. Economic value of wood fuel (Estimates in $/ha/year, $2005)

Latitude	Country	2005[a]	2050 A1FI[b]	2050 A2[b, c]	2050 B1[b]	2050 B2[b]
35 to 45	Greece	0.28	0.28	0.28	0.28	0.28
	Italy	0.01	0.01	0.01	0.01	0.01
	Portugal	0.16	0.21	0.22	0.18	0.18
	Spain	0.30	0.30	0.30	0.27	0.30
	Albania	1.33	1.32	1.34	1.21	1.26
	Bosnia and Herzegovina	4.73	5.80	5.72	4.08	5.16
	Bulgaria	1.36	1.67	1.64	1.17	1.48
	Serbia and Montenegro	0.01	0.01	0.01	0.01	0.01
	Turkey	n.s.	n.s.	n.s.	n.s.	n.s.
	TFRY Macedonia	n.s.	n.s.	n.s.	n.s.	n.s.
	Regional Average	0.40	0.65	0.53	0.35	0.42
45 to 55	Austria	20.59	25.23	24.88	17.76	22.44
	Belgium	2.37	2.49	2.41	1.36	1.38
	France	0.84	0.67	0.68	0.59	0.59
	Germany	0.14	0.12	0.12	0.10	0.10
	Ireland	0.06	0.05	0.05	0.03	0.04
	Luxembourg	14.13	14.16	14.15	14.11	14.12
	Netherlands	5.51	5.05	6.56	4.59	4.59
	Switzerland	1.32	1.44	1.44	1.34	1.18
	Croatia	4.62	4.32	4.49	3.74	3.78
	Czech Republic	4.84	4.53	4.71	3.92	3.97
	Hungary	6.46	6.05	6.28	5.23	5.29
	Poland	0.51	0.48	0.50	0.42	0.42
	Romania	0.46	0.43	0.44	0.37	0.37
	Slovakia	0.09	0.10	0.10	0.07	0.09
	Slovenia	5.92	5.54	5.75	4.79	4.85
	Regional Average	2.56	3.14	2.74	1.94	2.17
55 to 65	Denmark	6.35	6.86	8.58	5.15	4.63
	United Kingdom	2.10	2.42	2.60	1.75	1.85
	Estonia	2.99	3.34	3.87	2.46	2.41
	Latvia	3.75	4.19	4.85	3.08	3.01
	Lithuania	1.52	1.70	1.97	1.25	1.22
	Regional Average	2.83	4.47	4.79	2.44	3.23
65 to 71	Finland	0.02	0.03	0.03	0.02	0.03
	Iceland	n.s.	n.s.	n.s.	n.s.	n.s.
	Norway	0.01	0.01	0.01	0.01	0.01
	Sweden	0.10	0.12	0.12	0.11	0.11
	Regional Average	0.05	0.09	0.09	0.09	0.09

Notes: [a] data from FAO; [b] EIBURS projections; [c] interpreted by the European Commission as the baseline scenario, i.e. the scenario characterized by policy inaction; n.a. not available; n.s. not significant

Table A5. Total economic value of wood forest products (Estimates in $/ha/year, $2005)

Latitude	Country	2005[a]	2050 A1FI [b]	2050 A2[b, c]	2050 B1 [b]	2050 B2 [b]
35 to 45	Greece	38	44	44	44	44
	Italy	323	176	175	161	175
	Portugal	491	811	848	700	701
	Spain	186	184	184	165	183
	Albania	8	11	7	8	7
	Bosnia and Herzegovina	75	173	104	69	85
	Bulgaria	71	132	79	52	64
	Serbia and Montenegro	51	60	39	51	47
	Turkey	25	32	20	23	23
	TFRY Macedonia	0	0	0	0	0
	Regional Average	160	168	139	134	141
45 to 55	Austria	1,551	1,418	1,398	997	1,261
	Belgium	7,207	9,186	6,130	5,036	5,113
	France	463	325	329	283	283
	Germany	1,502	1,268	1,262	994	1,062
	Ireland	756	677	659	476	586
	Luxembourg	2,485	1,332	1,331	1,327	1,329
	Netherlands	10,117	16,999	22,088	15,440	15,439
	Switzerland	1,641	1,068	1,066	991	871
	Croatia	160	206	160	141	145
	Czech Republic	592	774	599	529	542
	Hungary	351	434	336	297	304
	Poland	231	297	230	203	208
	Romania	133	175	135	119	122
	Slovakia	531	1,009	605	394	485
	Slovenia	541	675	523	461	473
	Regional Average	819	824	777	584	633
55 to 65	Denmark	930	1,061	1,576	945	851
	United Kingdom	937	1,509	1,364	915	967
	Estonia	223	364	369	183	264
	Latvia	332	540	548	272	391
	Lithuania	168	274	278	138	199
	Regional Average	466	749	682	401	503
65 to 71	Finland	536	873	852	786	830
	Iceland	17	14	13	12	13
	Norway	199	312	259	287	296
	Sweden	479	775	765	669	707
	Regional Average	456	749	730	668	701

Notes: [a] data from FAO; [b] EIBURS projections; [c] interpreted by the European Commission as the baseline scenario, i.e. the scenario characterized by policy inaction; n.a. not available; n.s. not significant

Table A6. Economic value of carbon sequestration (Estimates in $/ha/year, $2005)

Latitude	Country	2005[a]	2050 A1FI[b]	2050 A2[b, c]	2050 B1[b]	2050 B2[b]
35 to 45	Greece	1,629	927	950	1,093	990
	Italy	2,785	1,585	1,622	1,744	1,660
	Portugal	899	512	523	748	575
	Spain	1,202	684	707	785	735
	Albania	1,629	927	950	1,093	990
	Bosnia and Herzegovina	1,321	927	950	1,093	990
	Bulgaria	1,629	927	950	1,093	990
	Serbia and Montenegro	1,629	927	950	1,093	990
	Turkey	1,629	927	950	1,093	990
	TFRY Macedonia	407	927	950	1,093	990
	Regional Average	1,476	927	950	1,093	990
45 to 55	Austria	4,885	3,061	3,102	3,323	3,185
	Belgium	2,185	1,369	1,374	1,551	1,371
	France	2,218	1,389	1,483	1,741	1,576
	Germany	2,271	1,423	1,544	1,962	1,693
	Ireland	2,342	1,467	1,523	1,744	1,605
	Luxembourg	5,402	3,385	3,487	3,418	3,205
	Netherlands	2,894	1,813	1,851	2,065	1,923
	Switzerland	4,915	3,079	3,150	3,450	3,263
	Croatia	5,402	3,384	3,487	3,418	3,205
	Czech Republic	5,402	3,384	3,487	3,418	3,205
	Hungary	5,402	3,385	3,487	3,418	3,205
	Poland	5,402	3,384	3,487	3,418	3,205
	Romania	5,402	3,384	3,487	3,418	3,205
	Slovakia	5,402	3,384	3,487	3,418	3,205
	Slovenia	5,402	3,385	3,487	3,418	3,205
	Regional Average	4,328	2,712	2,795	2,879	2,684
55 to 65	Denmark	2,507	1,441	1,510	1,827	1,618
	United Kingdom	2,932	1,685	1,740	1,999	1,822
	Estonia	2,719	1,563	1,625	1,913	1,720
	Latvia	2,719	1,563	1,625	1,913	1,720
	Lithuania	2,719	1,563	1,625	1,913	1,720
	Regional Average	2,719	1,563	1,625	1,913	1,720
65 to 71	Finland	926	532	560	823	648
	Norway	1,691	972	996	1,111	1,037
	Sweden	1,289	741	733	1,043	824
	Regional Average	1,302	748	763	992	836

Notes: [a] projections by Tavoni et al. (2007).
[b] projections by CLIBIO based on CASES (reference)

Table A7. A comparison of the physical changes of forest areas, forestry production and carbon stock under IPCC storylines in 2050

Physical indicators	Latitude classification	A1 vs. A2 (2050)	B1 vs. A2 (2050)	B2 vs. A2 (2050)
Extent of forest area	Mediterranean Europe	82.6%	129.1%	133.9%
	Central-Northern Europe	81.7%	116.0%	125.9%
	Northern Europe	68.3%	111.0%	127.9%
	Scandinavian Europe	102.0%	102.3%	98.0%
Production of industrial roundwood	Mediterranean Europe	79.9%	113.6%	124.2%
	Central-Northern Europe	81.0%	79.7%	102.4%
	Northern Europe	59.7%	69.3%	83.7%
	Scandinavian Europe	104.3%	96.2%	94.2%
Production of wood pulp	Mediterranean Europe	94.0%	126.8%	134.4%
	Central-Northern Europe	87.7%	82.4%	103.2%
	Northern Europe	78.7%	80.1%	108.3%
	Scandinavian Europe	104.8%	93.8%	94.2%
Production of recovered paper	Mediterranean Europe	94.3%	126.4%	139.2%
	Central-Northern Europe	86.8%	86.9%	105.8%
	Northern Europe	81.6%	81.6%	109.1%
	Scandinavian Europe	105.6%	96.8%	95.0%
Production of sawnwood	Mediterranean Europe	73.5%	109.4%	121.4%
	Central-Northern Europe	88.5%	82.0%	103.3%
	Northern Europe	59.8%	69.6%	84.2%
	Scandinavian Europe	104.5%	95.0%	94.2%
Production of wood-based panels	Mediterranean Europe	83.3%	117.1%	129.3%
	Central-Northern Europe	87.4%	85.6%	106.4%
	Northern Europe	71.9%	74.8%	98.0%
	Scandinavian Europe	105.8%	89.8%	94.3%
Production of paper and paper board	Mediterranean Europe	94.2%	125.6%	138.1%
	Central-Northern Europe	86.9%	86.8%	104.3%
	Northern Europe	80.6%	80.6%	107.9%
	Scandinavian Europe	104.6%	93.2%	94.0%
Production of wood fuel	Mediterranean Europe	72.9%	108.9%	121.0%
	Central-Northern Europe	80.6%	77.4%	99.8%
	Northern Europe	53.5%	57.5%	76.4%
	Scandinavian Europe	104.7%	95.2%	94.3%
Carbon stock	Mediterranean Europe	78.0%	119.6%	120.7%
	Central-Northern Europe	74.3%	110.6%	78.8%
	Northern Europe	61.7%	104.0%	87.7%
	Scandinavian Europe	98.4%	130.3%	106.9%

Table A8. A comparison of total economic value ($/yr) changes derived from Forest EGS under IPCC storylines in 2050

Forest EGS	Geographical groupings	A1 vs. A2 (2050)	B1 vs. A2 (2050)	B2 vs. A2 (2050)
Industrial roundwood	Mediterranean Europe	98.0%	112.5%	120.5%
	Central-Northern Europe	93.8%	94.8%	107.7%
	Northern Europe	61.1%	54.4%	84.3%
	Scandinavian Europe	105.3%	182.4%	94.8%
Wood pulp	Mediterranean Europe	96.7%	125.2%	135.3%
	Central-Northern Europe	82.1%	86.1%	100.2%
	Northern Europe	86.2%	86.9%	114.9%
	Scandinavian Europe	104.9%	95.8%	94.5%
Recovered paper	Mediterranean Europe	99.4%	131.1%	141.7%
	Central-Northern Europe	76.4%	84.3%	98.3%
	Northern Europe	79.2%	78.3%	105.9%
	Scandinavian Europe	107.4%	94.3%	95.7%
Sawnwood	Mediterranean Europe	75.4%	99.1%	118.4%
	Central-Northern Europe	89.2%	84.9%	102.8%
	Northern Europe	55.5%	68.8%	76.0%
	Scandinavian Europe	103.9%	95.9%	93.9%
Wood-based panels	Mediterranean Europe	90.8%	121.0%	134.4%
	Central-Northern Europe	93.4%	92.2%	107.2%
	Northern Europe	60.4%	68.1%	82.1%
	Scandinavian Europe	104.8%	86.5%	93.3%
Paper and paper board	Mediterranean Europe	96.4%	125.9%	138.0%
	Central-Northern Europe	88.5%	89.6%	103.9%
	Northern Europe	76.5%	76.5%	102.4%
	Scandinavian Europe	104.5%	40.2%	93.9%
Wood fuel	Mediterranean Europe	69.9%	89.9%	114.6%
	Central-Northern Europe	90.6%	79.5%	97.6%
	Northern Europe	57.5%	67.6%	78.4%
	Scandinavian Europe	103.9%	99.3%	94.3%
Carbon stock	Mediterranean Europe	81.2%	145.4%	138.9%
	Central-Northern Europe	73.5%	119.6%	119.4%
	Northern Europe	66.2%	130.6%	135.6%
	Scandinavian Europe	100.6%	142.0%	109.6%

Table A9. A comparison of productivity value ($/ha/yr) changes derived from Forest EGS under IPCC storylines in 2050

Forest EGS	Latitude classification	A1 vs. A2 (2050)	B1 vs. A2 (2050)	B2 vs. A2 (2050)
Industrial roundwood	Mediterranean Europe	118.7%	87.1%	90.0%
	Central-Northern Europe	114.9%	81.7%	85.6%
	Northern Europe	89.5%	49.0%	65.9%
	Scandinavian Europe	103.2%	94.7%	96.7%
Wood pulp	Mediterranean Europe	118.9%	96.8%	100.1%
	Central-Northern Europe	93.5%	70.2%	76.4%
	Northern Europe	150.0%	78.3%	89.8%
	Scandinavian Europe	103.3%	93.4%	96.6%
Recovered paper	Mediterranean Europe	120.2%	101.7%	105.5%
	Central-Northern Europe	80.8%	66.7%	73.1%
	Northern Europe	132.6%	69.8%	82.6%
	Scandinavian Europe	106.3%	91.8%	98.2%
Sawnwood	Mediterranean Europe	122.2%	78.5%	87.0%
	Central-Northern Europe	113.3%	74.2%	82.3%
	Northern Europe	91.6%	50.0%	66.9%
	Scandinavian Europe	102.0%	93.5%	95.9%
Wood-based panels	Mediterranean Europe	120.7%	96.3%	101.6%
	Central-Northern Europe	119.0%	80.6%	86.8%
	Northern Europe	97.6%	52.9%	69.0%
	Scandinavian Europe	103.1%	84.5%	95.4%
Paper and paper board	Mediterranean Europe	120.3%	98.6%	103.3%
	Central-Northern Europe	103.1%	74.5%	80.6%
	Northern Europe	127.0%	67.1%	80.4%
	Scandinavian Europe	102.7%	91.0%	96.0%
Wood fuel	Mediterranean Europe	124.3%	67.3%	80.1%
	Central-Northern Europe	114.4%	70.8%	79.3%
	Northern Europe	93.4%	50.8%	67.4%
	Scandinavian Europe	101.9%	96.9%	96.3%
Carbon stock	Mediterranean Europe	97.5%	115.0%	104.2%
	Central-Northern Europe	97.0%	103.0%	96.0%
	Northern Europe	96.2%	117.7%	105.9%
	Scandinavian Europe	98.1%	130.0%	109.6%

Table A10: Economic values derived from three forest ecosystem services in Europe

Country	Regulating Service (2005 Million US$/yr)	Cultural Services (2005 Million US$/yr)	Provisioning services (2005 Million US$/yr)	Total (2005 Million US$/yr)
Albania	305	0.3	6	1,300
Austria	4,451	91	5,990	24,949
Belgium	344	75	4,807	6,339
Bosnia&Herzegovina	839	0.2	202	3,761
Bulgaria	1,393	40	256	6,200
Croatia	2,721	8.2	343	11,884
Czech Republic	3,375	73	1,568	15,946
Denmark	296	57	465	1,776
Estonia	1,465	2.3	510	6,723
Finland	4,913	3.3	12,067	32,897
France	8,137	831	7,204	42,529
Germany	5,933	2,440	16,636	44,228
Greece	1,442	89	141	6,341
Hungary	2,518	107	693	11,474
Ireland	370	0.03	506	2,072
Italy	6,557	1,734	3,225	32,753
Latvia	1,887	1.1	977	8,976
Lithuania	1,347	7.8	354	6,069
Luxembourg	111	5.2	216	691
Netherlands	249	166	3,693	4,915
Norway	3,744	1.2	1,863	17,737
Poland	11,714	224	2,127	52,007
Portugal	802	42	1,859	5,302
Romania	8,118	143	848	35,403
Serbia&Montenegro	1,035	0.3	137	4,525
Slovakia	2,458	35	1,025	11,481
Slovenia	1,611	17	684	7,529
Spain	5,078	1,034	3,337	25,897
Sweden	8,371	149	13,200	48,834
Switzerland	1,416	46	2,003	8,050
Turkey	3,909	0.02	256	16,827
United Kingdom	1,967	734	2,665	11,739

Table A11: Estimated value of freshwater ecosystem services in Europe

Country	Mean value [$/ha year]	Total area [ha]	Aggregated value [Million US$2003/year]
Austria	17,969	95,685	1,719
Belgium	113,286	24,762	2,805
Bulgaria	69,497	111,972	7,782
Croatia	166,508	71,551	11,914
Czech Republic	14,589	60,688	885
Denmark	11,266	90,495	1,020
Estonia	1,205	396,919	478
Finland	1,779	5,396,898	9,599
France	10,851	400,351	4,344
Germany	14,935	518,158	7,739
Greece	81,645	132,851	10,847
Hungary	5,867	279,976	1,642
Ireland	9,155	1,271,368	11,640
Italy	200,278	233,984	46,862
Latvia	2,396	272,944	654
Lithuania	1,789	182,333	326
Luxemburg	121,994	733	89
Netherlands	20,734	226,065	4,687
Norway	3,672	1,005,407	3,692
Poland	6,150	556,487	3,423
Portugal	275,265	55,567	15,296
Romania	4,495	683,155	3,071
Slovakia	12,728	30,435	387
Slovenia	30,095	10,307	310
Spain	117,314	342,307	40,157
Sweden	5,926	6,523,231	38,658
Switzerland	19,624	52,326	1,027
UK	8,819	747,987	6,596

CURRICULUM VITAE

EDUCATION

Ph.D. in Science and Management of Climate Change, Department of Economics, Ca'Foscari University of Venice - Italy, *September 2007 - March 2011(Expected).*

M.Sc. in Environmental Science, with Specialization in Environmental Economics and Natural Resources, Department of Environmental Science and Group of Environmental Economics and Natural Resources, Wageningen University - the Netherlands, *September 2004 - June 2006*

B.A. in Economics and Finance, School of Economics and Business Management, Shenyang University of Technology - P. R. China, *September 1999 - July 2003*

EXPERIENCE

Fondazione ENI Enrico Mattei (FEEM), Venice, Italy

Researcher, Ecosystems and Biodiversity Economics Division, Sustainable Development Programme, October 2006 - present

Intern, Ecosystems and Biodiversity Economics Division, Sustainable Development Programme, February -July 2006

Worked extensively on the EU projects related to the following topics: economic valuation of biodiversity and ecosystem services, damage assessment of environmental impacts and social dimension of biodiversity policy. Wrote research proposals, reports and peer-reviewed papers. Took part in project coordination.

European Commission (EC), Brussels, Belgium

Economic consultant, DG Environment, January 2011 - present

Participated in the project "Overall Economic Value of Natura 2000 Benefits", provided technical support on value transfer techniques and the valuation of climate change regulation benefits from the Natura 2000 sites in Europe.

Project co-coordinator & Economic consultant, DG Environment, February - August, 2010

Coordinated the project of "The Social Dimension of Biodiversity Policy" and conducted economic analysis of biodiversity benefits to vulnerable groups in the EU and beyond. The results of this study have been presented in the CBD-COP10 meeting held in Nagoya, Japan.

Economic consultant, DG Environment, January - May, 2008

Participated in a couple of research projects that provided background studies for the EU to be presented in the CBD-COP 9 meeting in Bonn, including (1) "The Cost of Policy Inaction (COPI): The case of not meeting the 2010 biodiversity target"; (2) The Economics of Ecosystems and Biodiversity (TEEB): "Review on the Economics of Biodiversity Loss– phase 1 (scoping) economic analysis and synthesis"

Environment Canada, Gatineau (Québec), Canada

Individual Contractor, Economic Analysis Directorate, January 2011 - present

Identified and captured studies to the Environmental Valuation Reference Inventory (EVRI) website.

Venice International University (VIU), Venice, Italy

Lecturer, Course of Globalization, Environment and Sustainable Development, 2009 - present

Lectured in Model III: China's challenges with respect to economic growth, environmental challenges and governance, and international cooperation for sustainable development.

Project Assistant & Researcher, TEN Center – Thematic Environmental Networks, 2006 - 2007

Worked as training assistant in the Sino-Italian Cooperation Program for Environmental Protection to organize training courses to the Chinese governmental officials and academies in the area of environment and sustainable development. Wrote confidential report on China's environmental problems and governance structure.

Basque Center for Climate Change (BC3), Bilbao, Spain
Economic consultant, for the BBVA-CLIMBE project, May 2010 - present
Led the research task on cost/benefit analysis of Costa Rica's alternative policy strategies to cope with climate change impact on tropical forests.

European Investment Bank (EIB), Luxemburg, Luxemburg
Researcher, Projects Directorate, January - December 2010
Investigator of the STAREBEI research project on the SOcial costs of CARBon in the context of climate change: Results from an ecosystem-servicES based perspective (SOCARBES).

University of Maryland, MD, USA
Visiting scholar, Department of Agricultural and Resource Economics, April - May, 2009

Ca'Foscari University of Venice, Venice, Italy
Research collaborator, Department of Economics, 2006-2009
Collaborated on the EIBURS project of Impacts of Climate Change and Biodiversity Effects and led the research line on the economic valuation of forest ecosystems in Europe. Wrote scientific reports to the European Investment Bank.

PUBLICATIONS AND RESEARCH

PEER-REVIEWED PUBLICATIONS

Chiabai, A., Travisi, C., Markandya, A., Ding, H., and P.A.L.D. Nunes (forthcoming) "Economic Assessment of Forest Ecosystem Services Losses: Cost of Policy Inaction", *Journal of Environmental and Resource Economics*

WORKING PAPERS

Ding, H., Silvestri, S. Chiabai, A. and P.A.L.D. Nunes (2010) "A Hybrid Approach to the Valuation of Climate Change Effects on Ecosystem Services: Evidence from the European Forests" *FEEM Working Paper No. 2010.050*

Ding, H., Nunes, P.A.L.D., and S. Teelucksingh (2010) "European Forests and Carbon Sequestration Services: An Economic Assessment of Climate Change Impacts", *FEEM Working Paper No. 2010.010*

Nunes, P.A.L.D., Ding, H. and A. Markandya (2009) "Economic Valuation of Marine Ecosystems", FEEM *Working Paper No. 2009.068*

Chiabai, A. , Travisi, C., Ding, H., Markandya, A., and P.A.L.D. Nunes (2009) "Economic Valuation of Forest Ecosystem Services: Methodology and Monetary Estimates", *FEEM Working Paper No.2009.012*

Ding, H., Nunes, P.A.L.D., and L. Onofri (2007) "An Economic Model for Bioprospecting Contracts", *FEEM Working Paper No.2007.102.*

Ding, H., Ruijs, A. and E.C., van Ierland (2007) "Designing a Decision Support System for Marine Reserves Management: An Economic Analysis for the Dutch North Sea", *FEEM Working Paper No. 2007.023.*

BOOK CHAPTERS AND MONOGRAPHS

Ding, H., Nunes, P.A.L.D. and S. Teelucksingh (2010) "European Forests and Carbon Sequestration Services: An Economic Assessment of Climate Change Impacts" in Pushpam and Wood (eds.) *Valuation of Regulating Services of Ecosystems: Methodology and Applications,* Routledge, ISBN: 978-0-415-56987-3

Nunes, P.A.L.D, Ding, H. and A. Markandya (2009) 'The Economic Valuation of Marine Ecosystems" in F. Briand (eds.) *Economic Valuation of Natural Coastal and Marine Ecosystems*, CIESM Workshop Monograph N° 37, pages. 23-34, Monaco.

RESEARCH REPORTS

Nunes, P.A.L.D., Ding, H., Ghermandi, A., Rayment, M., Varma, A., Pieterse, M., Kapthengst, T., Lago, M., Davis, M., Boteler, B., Naumann S., McConville, A. J. and P. ten Brink (2010) The Social Dimension of Biodiversity Policy: The Final Report. ENV.G.1/FRA/2006/0073 – 2nd, Contract: 070307/2009/550766/ETU/F1, pages vii-179, Italy, Venice 2010

Carraro, C., Bosello, F., Nunes, P.A.L.D., De Cian, E., Ding, H., Eboli, F., Ghermandi, A., Lugato, E., Rosa, N.R. Parrado, R. and S. Silvestri (2009) "The Impacts of Climate Change and Biodiversity Effects: Final Year Report", ix + 225 pages, European Investment Bank, Luxembourg.

Carraro, C., Bosello, F., Nunes, P.A.L.D., Chiabai, A., Ding, H., Ghermandi, A., Lugato, E., Macagno, G., Ojea, E. and S. Silvestri (2008) "The Second Annual EIBURS-CLIBIO Report on the Impacts of Climate Change and Biodiversity Effects: 2007-2008", Department of Economics, Ca'Foscari University of Venice, Italy and the European Investment Bank, Luxemburg.

Braat, L., ten Brink, P., Bakkes, J., Bolt, K., Braeuer, I., ten Brink, B., Chiabai, A., Ding, H., Gerdes, H., Jeuken, M., Kettunen, M., Kirchholtes, U., Klok, C., Markandya, A., Nunes, P., van Oorschot, M., Peralta-Bezerra, N., Rayment, M., Travisi, C., and M. Walpole (2008) "The Cost of Policy Inaction: The case of not meeting the 2010 biodiversity target" for the European Commission, DG Environment under contract: ENV.G.1/ETU/2007/0044 (Official Journal reference: 2007 / S 95 – 116033).

Carraro, C., Bosello, F., Nunes, P.A.L.D., Chiabai, A., and H. Ding (2007) "The First Annual EIBURS-CLIBIO Report on the Impacts of Climate Change and Biodiversity Effects: 2006-2007", Department of Economics, Ca'Foscari University of Venice, Italy and the European Investment Bank, Luxemburg.

Ruijs, A., Ding, H., Punt, M.J. and E.C., van Ierland (2007) "Marine Biodiversity and Ecosystem Functioning: Responsive Mode Project 5.1 Decision Support System Progress Report", MarBEF Project: GOCE-CT-2003-505446, EU Network of Excellence Sustainable Development, Global Change and Ecosystems.

POLICY BRIEFS

Nunes, P.A.L.D. and H. Ding (2009) "Economic Assessment of Climate Change Caused Impacts on Biodiversity and Ecosystem Services", FEEM Policy Brief 08.2009

CONFERENCE PRESENTATIONS

"Modeling Climate Change and Biodiversity Effects on the Value of Ecosystem Goods and Services: An Empirical Investigation on the European Forest Ecosystem", 12th BIOECON conference, Venice-Italy, 27-28 September, 2010

"Modeling the links between biodiversity, ecosystem services and human wellbeing in the context of climate change: results of an econometric exercise to the European forests.", Belpasso summer school, Belpasso-Italy, 12-19 September, 2010

"Assessing the Impacts of Biodiversity and Ecosystem Service in Response to Climate Change in Europe: Results from Partial-General Equilibrium Valuation Model", oral presentation in the Fourth World Congress of Environmental and Resource Economists, Montreal - Canada, 28 June - 2 July, 2010

"Economic modeling of biodiversity in the scenario of global change: results from a European study on forests", 11th BIOECON conference, Venice-Italy, 21-22 September, 2009

"A hybrid approach to the valuation of climate change effects on ecosystem services: evidence from the European forests", 11th BIOECON Conference, Venice - Italy, 21-22 September, 2009

"Economic Valuation of Forest Ecosystem Services: Methodology and Monetary Estimates", 17th annual EAERE conference, Amsterdam - The Netherlands, 24-27 June, 2009

"Assessing the Climate Change Impact on European Forest Ecosystem", 17th annual EAERE conference, Amsterdam - The Netherlands, 24-27 June, 2009

"An Environmental Economics Outlook of the Climate Change Impact on Carbon Regulation Services-Evidence from the European Forest Ecosystem", the SCAPES workshop, Bangalore - India, 14-15 June 2009,

"Economic Valuation of Forest Ecosystem Services: Methodology and Monetary Estimates", 17h annual EAERE conference, Amsterdam - The Netherlands, 24-27 June 2009

"An Economic Model for Bioprospecting Contracts", oral presentation (by co-author) of the 17h annual EAERE conference, Amsterdam - The Netherlands, 24-27 June 2009

"Designing a Decision Support System for Marine Reserves Management:", International Marine Conservation Congress (IMCC), Washington DC – USA, 19-24 May, 2009

"An Environmental Economics Outlook of the Climate Change Impact on Forest Ecosystems and Biodiversity: results from an empirical application to the Europe", the international workshop on "SOCIO-ECONOMIC DRIVERS OF CLIMATE CHANGE" Department of Economics, Ca' Foscari University - Venice, Italy 11-12 December, 2008

"Economic Valuation of Marine Environmental Damages: Assessment of Non-use Value Losses Involved with the Prestige Oil Spill by Means of Value Transfer", World Conference on Marine Biodiversity (WCMB), Valencia – Spain, 11-15 November, 2008

"An Environmental Economics Outlook of the Climate Change Impact on Forest Biodiversity and Human Wellbeing: Results from a MEA Application to Europe", 10th annual BIOECON conference, Sidney Sussex College of Cambridge – UK, 28-30 September, 2008

"Linking Biodiversity Indicators to Human Wellbeing: An Econometric Analysis of Climate Change Impacts on European Forest Biodiversity", 2008 International Society for Ecological Economics (ISEE) Conference, Nairobi – Kenya, 07-11 August, 2008

"An Economic Model for Bioprospecting Contracts", European Summer School in Resource and Environmental Economics: Trade, Property Rights and Biodiversity, VIU campus, Venice – Italy, 04 -10 July, 2007

"Designing a Decision Support System for Marine Reserves Management: An Economic Analysis for the Dutch North Sea", 15th Annual Conference of the "European Association of Environmental and Resource Economists"(EAERE 2007), Thessaloniki – Greece, 27-30 June, 2007

"Spatial Allocation of Marine Reserves: an Economic Analysis for the Dutch North Sea", 9th Biennial Conference of International Society for Ecological Economics (ISEE) on "Ecological Sustainability and Human Well-Being", New Delhi – India, 15-19 December, 2006

"Is Biocontracting an Efficient Market-based Policy Instrument for Biodiversity Conservation?", 8th Annual BIOECON Conference on "Economic Analysis of Ecology and Biodiversity", Kings College of Cambridge – UK, 29-30 August, 2006

MEDIA

Ding, H. (2010) "China's Environment in a Globalizing World - An Overview on Environmental Issues in the Modern China", *The XXVI edition of "il Quaderno",* Publications & Media Relations Executive of China-Italy Chamber of Commerce (CICC), Beijing.

CURRENT RESEARCH

Economic valuation of biodiversity and ecosystem services and links to human livelihoods; Environmental policy design for coping with global change and promoting biodiversity conservation and poverty alleviation, with a particular interest in developing countries.

POSTGRADUATE TRAINING

2010 Belpasso International Summer School on the Economics of Ecosystem Services and Biodiversity Conservation, jointly organized by the Faculty of Agriculture, the University of Catania, Belpasso, Sicily and the European Association of Environmental and Resource Economists (EAERE), Belpasso - Italy, 12-19 September 2010 (Scholarship holder);

EXIOPOL Summer School on Environmental Accounting: Externality Valuation and Input-Output Tools for Policy Analysis, organized by the EU-FP6 EXIOPOL Integrated Project and held in Venice - Italy, 11-17 July, 2010 (Scholarship holder);

State-of-the-Art Stated Preferences Modelling course (programming using R and LIMDEP), Umeå University and the Swedish University of Agricultural Sciences, Umeå - Sweden, 3-7 May, 2010;

SUSDIV summer courses on Sustainable Development and Diversity, organized by University of the Basque Country, San Sebastian - Spain, 1-3 July, 2008 (Scholarship holder);

EAERE-FEEM-VIU summer courses on 'Economics of Trade, Property Rights and Biodiversity', organized by European Annual Summer School in 'Resource and Environmental Economics', VIU campus, Venice - Italy, 4-10 July, 2007 (Scholarship holder)

HONORS AND AWARDS

STAREBEI scholarship granted by the European Investment Bank (EIB), Luxembourg, 2010;

PhD research scholarship granted by FEEM, Venice - Italy, 2007-2009;

One-year research fellowship granted by Venice International University - Italy, 2006/2007;

Scholarship granted by “Anne van den Ban Fund”, Wageningen - the Netherlands, 2005;

Two scholarships for the 3rd best students’ academic achievement for the academic year 1999/2000 and 2001/02, Shenyang University of Technology, P.R.China;

Outstanding Leadership Award awarded by the student council for the academic year 1999/2000, 2000/01 and 2001/02, Shenyang University of Technology, P.R.China;

Student representative of Shenyang University of Technology for attending the governmental conference of ‘Outlook of the Economic Development in China’ held in the provincial government, Shenyang, Liaoning province, P.R.China, 1999

PERSONAL SKILLS

LANGUAGES

Chinese Mandarin:	Native
English:	Fluent – Written/Oral
Italian:	Conversational

COMPUTER SKILLS

Knowledge of Stata, R, LIMDEP, SPSS, GAMS, EndNote, and Microsoft Office™ tools (incl. Word, Excel and PowerPoint).

OTHER COMPETENCES

Team spirit and strong ability to adapt to multicultural environment gained through my overseas study experience and work experience in a large number of international research projects.

Good technical and organizational skills in terms of writing research proposals, reports and peer-reviewed papers, project negotiations and coordination, gained through participating in the application of and research in a considerable number of EC-DG-ENV and EC-FP6/7 research projects, since 2006.